Technical Report CERC-93-4
May 1993

US Army Corps
of Engineers
Waterways Experiment
Station

Coastal Engineering Research Program

SUPERDUCK Beach Sediment Sample Experiment: Beach Profile Change and Foreshore Sediment Dynamics

by *Donald K. Stauble, Garry W. Holem,*
Mark R. Byrnes, Fred J. Anders,
Edward Meisburger
Coastal Engineering Research Center

Approved For Public Release; Distribution Is Unlimited

Prepared for Headquarters, U.S. Army Corps of Engineers

Coastal Engineering Research Program

Technical Report CERC-93-4
May 1993

SUPERDUCK Beach Sediment Sample Experiment: Beach Profile Change and Foreshore Sediment Dynamics

by Donald K. Stauble, Garry W. Holem,
Mark R. Byrnes, Fred J. Anders,
Edward Meisburger

Coastal Engineering Research Center

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

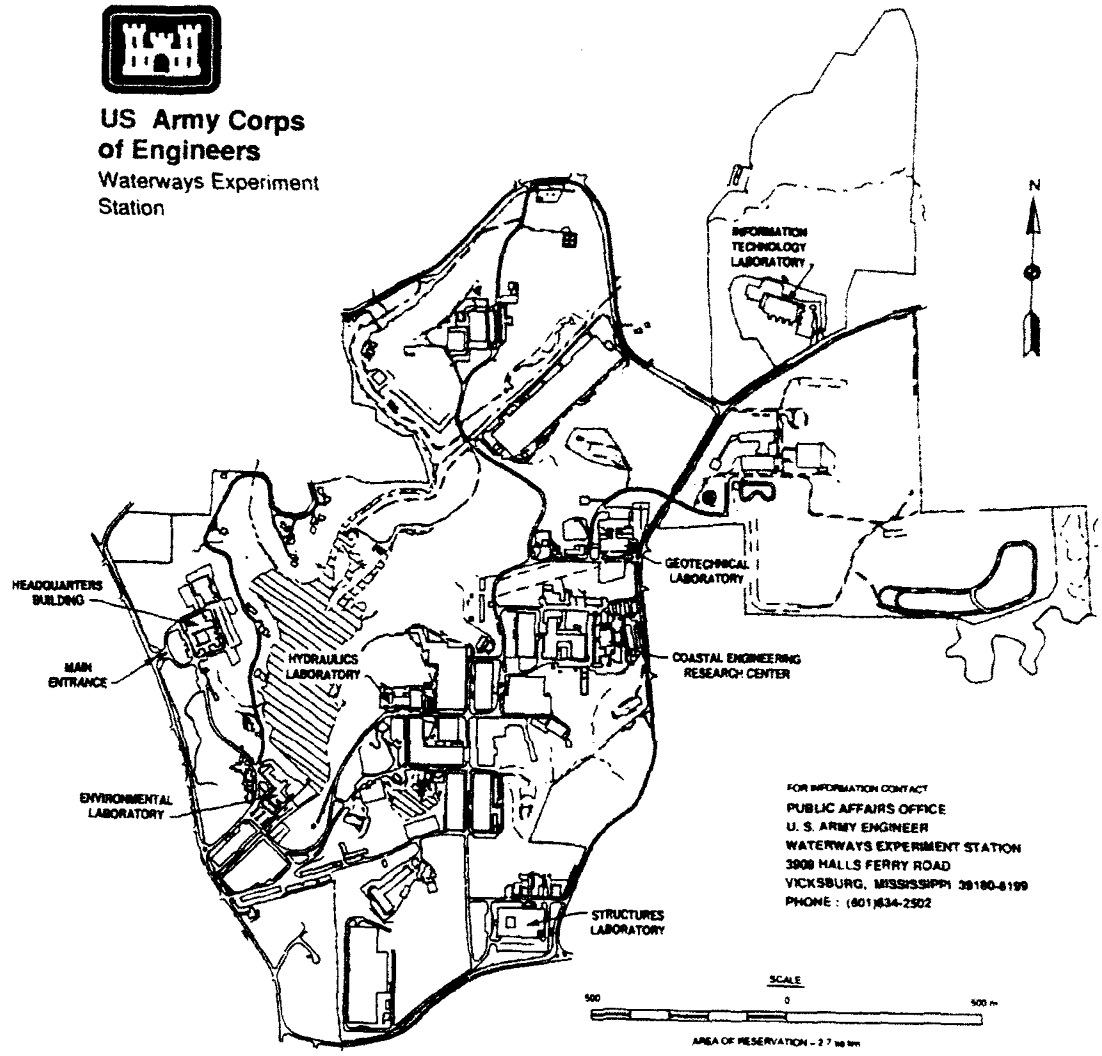
Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Under Work Units 31665 and 32525

US Army Corps of Engineers
Waterways Experiment Station



Waterways Experiment Station Cataloging-in-Publication Data

Stauble, Donald K.
SUPERDUCK beach sediment sample experiment : beach profile change and foreshore sediment dynamics / by Donald K. Stauble ... [et al.], Coastal Engineering Research Center; prepared for U.S. Army Corps of Engineers.
49 p. : ill. ; 28 cm. — (Technical report ; CERC-93-4)
Includes bibliographical references.
1. Coast changes — North Carolina. 2. Sedimentation and deposition — Atlantic Coast (N.C.) 3. Beach erosion — North Carolina. 4. Storm surges — Environmental aspects. I. Stauble, Donald K. II. United States. Army. Corps of Engineers. III. Coastal Engineering Research Center (U.S.) IV. U.S. Army Engineer Waterways Experiment Station. V. Coastal Engineering Research Program. VI. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; CERC-93-4.
TA7 W34 no.CERC-93-4

Contents

List of Figures

List of Tables

Preface

This report provides an analysis of data collected during a major field experiment at the U.S. Army Engineer Coastal Engineering Research Center (CERC) Field Research Facility (FRF). Data collection and analysis were authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Civil Works Research Work Unit 31665, "Barrier Island Sedimentation Studies." Publication was through Civil Works Research Work Unit 32525, "Field Research Facility Analysis." Funds were provided through the U.S. Army Engineer Waterways Experiment Station (WES), CERC under the Coastal Engineering Research Program, Dr. C. L. Vincent, former Program Manager and Ms. Carolyn Holmes, Program Manager. The field experiment was designed and directed by Dr. Suzette Kimball, University of Virginia, formerly CERC. HQUSACE Technical Monitors were Messrs. John C. Lockhart and Mr. John G. Housley.

This report was prepared by Dr. Donald K. Stauble, CERC, Mr. Garry W. Holem, U.S. Army Engineer District, Jacksonville, formerly CERC, Dr. Mark R. Byrnes, Louisiana Geological Survey, formerly CERC, Mr. Fred J. Anders, New York Department of State, Division of Waterfront Revitalization and Coastal Zone Management, formerly CERC, and Mr. Edward P. Meisburger, CERC. The work was conducted under the direct supervision of Dr. Steven A. Hughes, former Chief, Coastal Processes Branch (CPB), and Ms. Joan Pope, Chief, Coastal Structures and Evaluation Branch (CSEB), and under the general supervision of Mr. H. Lee Butler, Chief, Research Division, Mr. Thomas W. Richardson, Chief, Engineering Development Division, Dr. James R. Houston, Director, CERC, and Mr. Charles C. Calhoun, Jr., Assistant Director, CERC. Mr. William A. Birkemeier, Chief, FRF, provided wave gage and bathymetry data, as well as helpful discussion and review. Ms. Claire Livingston and Mr. Brian Williams, CSEB, assisted with graphics and compilation of this report.

At the time of publication of this report, Director of WES was Dr Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

1 Introduction

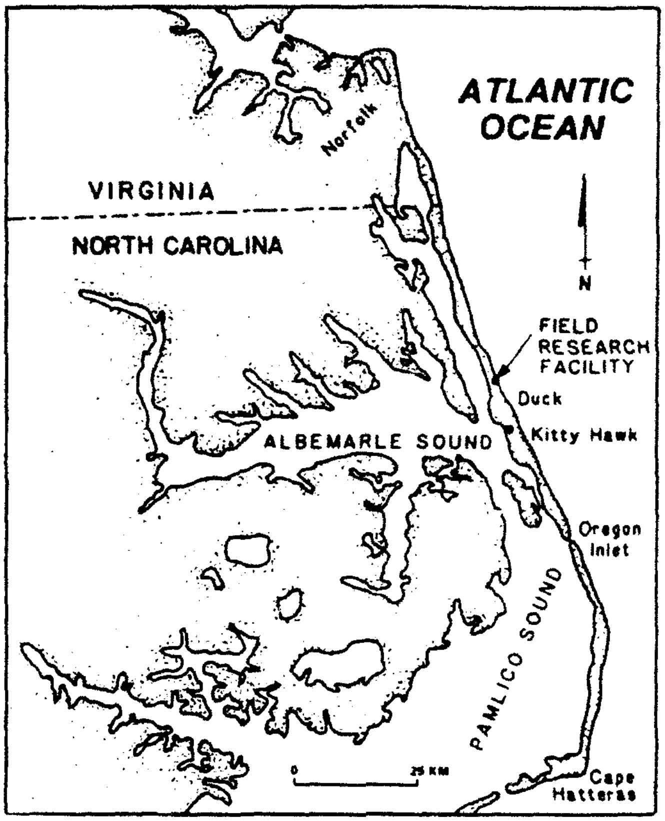
Most major morphologic beach changes occur as a result of high-energy storm events and elevated water levels. High energy conditions during tropical and extratropical storms can produce high winds, waves, and storm surge that mobilize and redistribute coastal sediment. These events typically occur over time frames on the order of hours or days, and can significantly alter beach morphology. Limited field data sets exist for developing an understanding of the process/response mechanisms controlling beach evolution.

To develop a better understanding of the dynamics of beach morphology response to high energy wave conditions, a field experiment was carried out as part of the SUPERDUCK experiments. SUPERDUCK represented a series of 32 field experiments designed to intensely study nearshore processes and associated sand transport; held during September and October, 1986 at the US Army Engineer Waterways Experiment Station (WES), Field Research Facility (FRF) located at Duck, N.C. (Crowson et. al 1989; Birkemeier et. al 1989). Participation in this experiment included engineers and scientists from the Coastal Engineering Research Center (CERC), other Corps of Engineers Division and District offices, six other Government agencies, and 10 universities.

The FRF is located on the Outer Banks of North Carolina, approximately 8 km (5.0 mi) north of Kitty Hawk (Figure 1). The site is on a relatively narrow sandy barrier between the Atlantic Ocean and Currituck Sound, which separates the barrier from the mainland. The study site was located approximately 500 meters north of the FRF research pier and encompassed a 55-m alongshore by 60-m across shore area of the beach.

The experiment described in this report was designed to collect sediment texture data the subaerial portion of the beach profile that is actively modified by nearshore waves and currents. Measurements of nearshore waves and beach profile change were used for examining changes in surface grain size distributions during extratropical storm conditions. The eleven day study period, from 12 October 1986 to 22 October 1986, included two extratropical storm events. One storm began on the morning of 10 October 1986 and lasted through 13 October 1986. A less severe storm system occurred from 18 October 1986 to 21 October 1986. During the test period wave characteristics were continuously monitored, beach and nearshore profiles were measured daily around low tide, and short sediment cores were obtained daily at 12 sampling stations in the study area.

Information collected during the experiment was initially summarized in Byrnes (1989). That report lists data on beach elevations, statistical sand size parameters, and wave



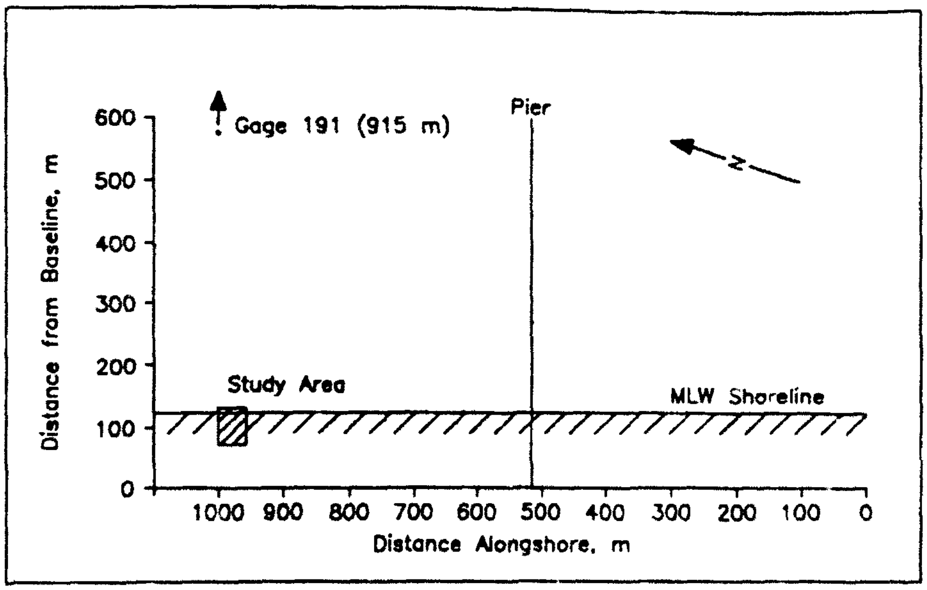


Figure 1. Location map of study area

characteristics during the eleven day study period, including an explanation of how the data were collected, their general characteristics, and some preliminary observations. In addition, a preliminary discussion of spatial and temporal variations in grain size parameters of the surficial sediment layer on the berm, upper swash, and lower swash beach zones is presented. This report extends beyond By ι.ɜs (1989) with a more detailed examination of profile, grain size, and wave characteristics and interactions which occurred during the period of study.

The report is divided into four sections, with the first section outlining the field sediment and profile sampling techniques and the laboratory analysis methods used. The next section gives the changes that occurred in the beach profile over the experimental period. Details of the change in the foreshore, where the sediment was collected, are reported. Changes in the nearshore portion of the profile are also examined and changes in the profile volume were calculated. The foreshore sediment dynamics are reported on in the next section, identifying the sediment types found during the experiment based on grain size distribution. Variability in grain size distribution was found in both the alongshore and cross shore direction. Composite sediment analysis provided a way to reduce this variability and show grain size trends. The final section provides a summary of the interaction of the storm processes with the profile and grain size response.

2 Sampling and Analysis Methods

Within the study area, six shore normal transect lines were established by survey (Figure 2). Each day during the 11-day study, near the time of predicted low tide, elevations of the beach surface were measured at six positions along each transect line using a rod and Zeiss Total Station. At the same time, short cores were obtained at locations within the berm, upper swash, and lower swash morphologic zones. Fluctuations in water level due to changing meteorological conditions prevented reoccupation of the precise sampling positions from day to day. However, each core was obtained from within the threc zones as they existed at the time of sampling. Locations and elevations of each station throughout the test period are contained in Byrnes (1989).

Sediment cores at each sampling station were obtained by pushing a short coring tube into the beach. The core tube consisted of a length of 7.6-cm (3-in.) stainless steel tubing with a plastic inner liner and a core catcher. After obtaining the cores, the plastic liner with enclosed sample was removed and capped for subsequent analysis. A total of 127 cores, having an average length of 39.6 cm (15.6 in.), were analyzed and subdivided into 127 surface samples and numerous below-surface samples for future analysis.

Each core was split in half lengthwise for visual data logging and sample extraction. Samples were selected to represent each lithologically distinct layer in a core. All cores contained at least two samples and as many as five samples per core were extracted. These were identified sequentially from the top to bottom by the letters a through e. Samples removed from cores were dried and a sub-sample from each was used for grain size analysis by sieving with an ATM Sonic Sifter device coupled to a Satorius microbalance and interfaced with an IBM PC for direct data transfer to size analysis software (Underwood 1989). Since the purpose of this report is to examine change in sand size associated with short-term, high energy storm events, surface samples were considered most indicative of beach response to coastal processes.

A statistical analysis of grain size for each sample was completed to determine the mean, median, standard deviation, skewness and kurtosis. All statistics were calculated using the method of moments, except median grain size, which is calculated as the mid-point of the distribution. A size frequency curve was prepared for each sample to visually illustrate characteristics of the size distribution. Appendix B of Byrnes (1989) lists statistical measures for all samples collected and analyzed. Table 1 lists statistical data calculated for each surface sample used in this report including the mean, median, sorting (standard deviation), skewness, and kurtosis using the method of moments and Folk's (1980) graphic method for median value

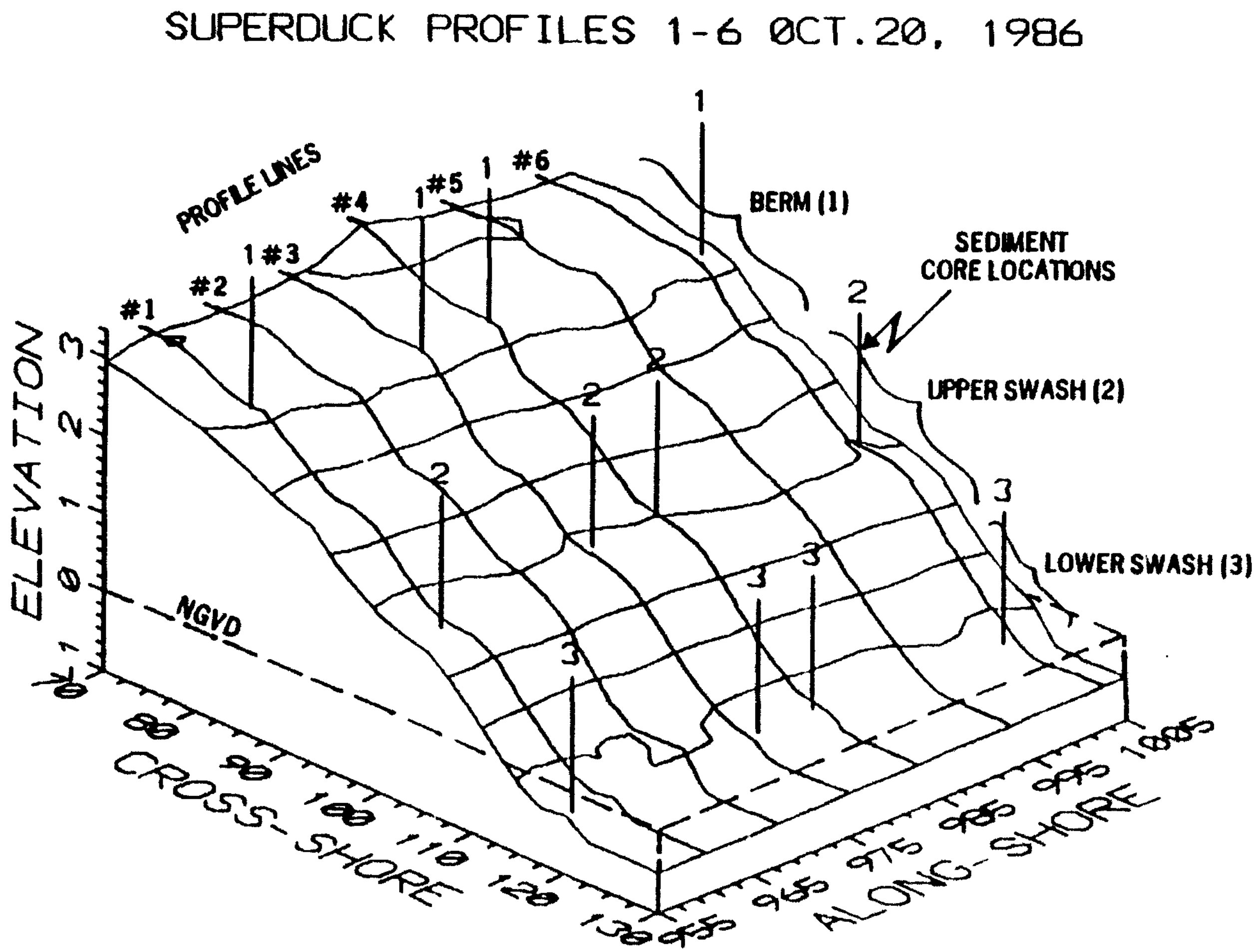


Figure 2. Experimental site sampling configuration

calculation, as well as the percentage of material in the gravel (> -1.0 ϕ or 2.0 mm), coarse sand (-1.0 to 1.0 ϕ or 2.0 to 0.5 mm), medium sand (1.0 to 2.0 ϕ or 0.5 to 0.25 mm) and fine sand (2.0 to 4.0 ϕ or 0.25 to 0.0625 mm) sizes based on the Wentworth size classification. No material was found to be coarser than -3.0 ϕ (8.0 mm) or finer than 4.0 ϕ (0.0625 mm) in any of the samples collected.

Nearshore and offshore wave climate are routinely sampled at the FRF. Additional sensors were installed during SUPERDUCK. Data from wave gage 191 were used to characterize temporal variations in significant wave height (H_{mo}) and spectral peak period (T_p) for the study area. H_{mo} is the significant wave height defined as the average of the highest one-third of the wave heights estimated from the spectral density (IAHR 1989). The gage was located 0.8 km seaward of the study site in the 8-m water depth. Wave height and period were recorded periodically and summarized for 6-hr periods from 9 October to 23 October 1986 (Byrnes 1989).

Two storm events (H_{mo} greater than 2 m) were recorded during the 9 to 23 October time interval. The first began early on 10 October, reached a peak on 11 October (3.1-m waves and 0.5-m storm surge), and maintained 2-m waves until late on 12 October. The second event was shorter and less intense. It began on 18 October and peaked on 19 October with wave heights around 2.3 m. Wave heights greater than 2 m were sustained for less than 24 hrs.

Nearshore bathymetry data were collected along 14 to 20 transects in the vicinity of the study area between 9 and 22 October. Profile data were obtained by FRF staff using the Coastal Research Amphibious Buggy (CRAB) in combination with a self-recording Zeiss Elta-II electronic total station (Birkemeier and Mason 1984). A total of 10 beach and nearshore surveys were conducted during the 14-day period to document morphologic response to wave and water level. Spatial and temporal variations in nearshore bathymetry were examined by developing two and three dimensional plots of survey data on successive days.

Table 1

Surface Sediment Sample Statistics

SAMPLE NUMBER	MOMENT MEASURES MEAN	STD DEV	SKEW	KURT	GRAPHIC MEDIAN	PERCENT COMPOSITION % GRAVEL	% C.SAND	% MEDIUM	% F.SAND
120101a	0.48	1.08	0.40	2.10	0.21	4.31	64.61	18.69	12.39
120102a	1.43	0.90	-0.68	2.71	1.70	0.28	11.73	39.10	31.06
120103a	-0.24	1.41	0.64	2.35	-0.64	32.44	45.02	10.71	11.83
120301a	0.12	1.10	0.84	2.33	-0.28	8.76	68.39	14.06	8.79
120302a	0.45	1.34	0.42	1.72	-0.16	7.58	56.79	13.45	22.18
120303a	-0.56	1.39	1.16	3.23	-0.99	48.60	33.63	5.96	11.81
120401a	0.62	0.89	0.28	2.35	0.47	1.78	65.64	25.17	7.41
120402a	1.12	0.99	-0.38	2.08	1.36	0.78	29.93	39.11	20.18
120403a	-0.61	1.51	0.84	2.52	-1.03	51.04	29.50	9.41	10.05
130101a	1.20	0.99	-0.52	2.39	1.46	0.98	39.11	34.60	25.31
130102a	1.02	0.86	-0.52	2.75	1.18	1.40	42.02	44.92	11.66
130103a	-0.22	1.38	0.60	2.40	-0.50	32.19	47.22	8.87	11.72
130301a	0.50	1.07	0.36	2.15	0.25	4.22	63.73	20.79	11.26
130302a	0.62	1.14	0.08	1.96	0.42	5.29	56.27	22.95	15.49
130303a	-0.60	1.48	0.80	2.53	-0.93	47.94	33.95	7.82	10.29
130401a	0.78	0.94	0.07	2.22	0.65	1.12	59.21	28.19	11.48
130402a	1.18	0.80	-0.42	2.75	1.29	0.57	38.50	46.97	13.96
130403a	0.18	1.51	0.10	1.79	-0.04	26.24	39.87	16.39	17.50
130601a	1.08	0.94	-0.30	2.23	1.23	0.60	43.59	38.97	16.84
130602a	0.72	1.14	-0.10	1.95	0.71	3.09	51.82	26.49	16.60
130603a	0.60	1.48	-0.12	1.75	0.39	15.54	41.53	15.76	27.17
140101a	0.88	0.94	-0.28	3.11	0.85	1.83	54.29	30.86	13.02
140102a	1.18	0.98	-0.58	2.53	1.42	1.92	38.10	36.98	23.00
140103a	-1.22	1.01	1.88	7.16	-1.40	69.32	25.53	2.22	2.93
140301a	0.09	1.04	0.80	3.10	-0.20	8.21	72.53	11.62	7.64
140302a	0.93	1.05	-0.16	1.99	0.95	2.38	48.83	30.09	18.70
140303a	0.06	1.59	0.32	1.80	-0.33	31.43	37.52	10.68	20.37
140401a	0.97	0.98	-0.38	2.67	1.04	2.50	46.48	36.19	14.83
140402a	1.49	0.87	-0.70	2.99	1.73	0.28	26.33	41.05	32.32
140601a	0.56	0.88	0.42	2.53	0.38	1.66	69.91	21.18	7.25
140602a	1.31	1.05	-0.76	2.64	1.67	2.56	31.20	35.43	30.81
140603a	-0.05	1.53	0.36	1.93	-0.29	31.89	41.34	10.51	16.26
150101a	1.52	0.82	-1.10	4.13	1.73	0.77	21.38	48.50	29.35
150102a	0.05	1.15	0.68	2.40	-0.34	15.23	60.90	16.06	7.81
150103a	0.45	1.41	0.32	1.65	-0.03	14.18	49.46	11.92	24.44
150301a	0.87	1.01	-0.04	1.93	0.87	1.29	51.84	32.18	14.69
150302a	1.05	1.08	-0.24	1.85	1.21	1.06	44.47	30.81	23.66
150303a	0.01	1.47	0.40	1.98	-0.41	26.93	44.47	12.87	15.73
150401a	0.94	0.89	-0.10	2.43	0.89	1.51	52.15	33.71	12.63
150402a	0.21	1.24	0.58	2.10	-0.34	11.28	59.72	15.44	13.56
150403a	0.30	1.25	0.36	2.27	-0.01	10.90	60.64	13.79	14.67
150601a	0.80	0.99	0.10	2.07	0.74	1.63	57.33	27.53	13.51
150602a	1.68	0.79	-1.26	4.92	1.85	0.61	16.85	43.86	38.68
150603a	0.32	1.44	0.42	1.73	-0.25	17.56	49.05	10.04	23.35

(Sheet 1 of 3)

Values given in terms of phi sizes

Table 1 (Continued)

SAMPLE NUMBER	MOMENT MEASURES MEAN	STD DEV	SKEW	KURT	GRAPHIC MEDIAN	PERCENT COMPOSITION % GRAVEL	% C.SAND	% MEDIUM	% F.SAND
160101a	1.37	0.73	-0.42	2.99	1.45	0.27	30.18	49.93	19.62
160102a	0.08	1.08	0.82	2.66	-0.28	10.71	67.43	14.23	7.63
160301a	0.69	1.09	0.02	1.97	0.63	4.47	54.04	28.00	13.49
160302a	0.03	0.65	1.48	5.50	-0.13	0.63	90.23	7.34	1.80
160303a	0.76	1.29	0.04	1.54	0.54	5.14	49.37	19.27	26.22
160401a	0.93	1.00	-0.40	2.83	0.94	4.13	52.01	33.58	14.41
160402a	0.10	0.76	1.34	4.27	-0.18	0.88	85.24	10.66	3.22
160403a	0.75	1.41	-0.22	1.68	0.94	13.73	36.92	21.95	27.40
160601a	0.65	0.93	0.22	2.63	0.49	1.59	64.93	24.61	8.87
160602a	1.24	1.25	-0.64	2.23	1.73	5.99	30.85	26.03	37.14
160603a	0.68	0.89	0.38	2.37	0.50	0.78	65.56	24.86	8.80
170101a	1.34	0.87	-0.54	2.69	1.53	0.43	33.03	41.78	24.76
170102a	1.24	0.99	-0.80	3.16	1.46	2.97	29.73	44.68	22.62
170103a	-0.49	0.90	1.02	3.34	-0.56	24.17	69.69	2.99	3.15
170301a	-0.61	0.91	1.50	5.61	-0.80	36.29	56.50	4.28	2.93
170302a	0.33	1.17	0.48	2.29	0.04	8.96	63.22	14.38	13.44
170303a	-0.45	1.69	0.82	2.19	-1.09	53.11	22.23	5.46	19.20
170401a	0.64	0.91	0.38	2.35	0.46	1.26	66.84	22.73	9.17
170402a	1.86	0.77	-1.90	8.18	2.02	1.49	8.48	38.78	51.25
170403a	-0.39	1.46	0.84	2.60	-0.78	42.37	37.77	6.68	13.18
170601a	0.40	0.94	0.60	2.65	0.14	3.24	71.91	16.66	8.19
170602a	1.32	0.90	-0.52	2.63	1.52	0.59	34.39	38.95	26.07
170603a	-0.17	1.69	0.64	1.83	-0.95	45.94	24.21	7.18	22.67
180101a	1.41	0.70	-0.32	2.72	1.50	0.00	28.96	51.17	19.87
180102a	1.48	1.13	-1.22	3.40	1.91	4.82	16.15	38.87	40.16
180103a	-1.11	1.81	1.22	2.80	-2.11	71.15	8.31	5.90	14.64
180301a	1.24	0.94	-0.46	2.25	1.51	0.74	36.12	39.98	23.16
180302a	0.83	1.19	-0.16	1.94	0.88	5.95	47.00	27.06	19.99
180303a	-0.60	1.73	0.70	2.00	-1.24	54.84	20.63	10.21	14.32
180401a	0.82	0.93	0.18	2.14	0.66	1.01	58.88	27.63	12.48
180402a	0.58	1.51	0.06	1.45	0.31	20.60	35.74	14.96	28.70
180403a	0.38	1.31	0.24	1.86	0.02	12.95	52.83	16.98	17.24
180401a	0.96	1.05	-0.36	2.72	0.98	3.64	46.96	32.03	17.37
180602a	0.65	1.48	-0.06	1.47	0.66	16.11	36.51	18.56	28.82
180603a	0.05	1.60	0.46	1.76	-0.59	30.71	37.16	9.33	22.80
190101a	0.82	0.99	0.02	2.00	0.74	1.55	55.19	29.58	13.68
190102a	0.03	1.33	0.80	2.24	-0.62	22.90	51.83	9.74	15.53
190103a	-0.55	1.65	1.10	2.65	-1.22	61.80	15.92	3.12	19.16
190301a	0.50	1.03	0.30	2.55	0.25	3.64	66.59	19.50	10.27
190302a	0.14	1.37	0.80	1.98	-0.61	15.16	55.77	8.36	20.71
190303a	0.08	1.50	0.56	1.78	-0.63	28.04	40.17	10.62	21.17
190401a	0.22	0.55	0.82	5.09	0.16	0.71	92.76	5.64	0.89
190402a	-0.16	1.49	0.88	2.12	-0.84	41.49	31.34	8.35	18.82
190403a	-0.11	1.77	0.58	1.64	-0.97	49.04	17.89	5.78	27.29
190601a	0.73	0.92	0.14	2.44	0.63	1.38	61.79	27.53	9.30
190602a	0.47	1.23	0.30	1.75	0.11	7.63	56.46	19.34	16.57
190603a	-0.47	1.08	1.22	4.20	-0.72	29.22	58.86	6.16	5.76

(Sheet 2 of 3)

Table 1 (Concluded)

SAMPLE NUMBER	MOMENT MEASURES MEAN	STD DEV	SKEW	KURT	GRAPHIC MEDIAN	PERCENT COMPOSITION % GRAVEL	% C.SAND	% MEDIUM	% F.SAND
200101a	-0.13	1.39	0.58	1.99	-0.62	38.94	34.62	15.81	10.63
200102a	-0.45	1.44	1.38	3.39	-1.04	52.88	28.29	2.31	16.52
200103a	-1.17	0.57	1.72	14.00	-1.15	63.77	35.40	0.16	0.67
200301a	0.19	0.99	0.88	3.02	-0.10	4.91	74.69	12.88	7.52
200302a	0.35	1.33	0.68	1.90	-0.21	6.69	62.10	7.84	23.10
200303a	0.23	1.45	0.62	1.81	-0.43	16.96	51.50	7.53	24.01
200401a	0.86	0.90	0.10	2.23	0.75	0.80	57.17	30.43	11.60
200402a	-0.13	1.37	1.12	2.65	-0.70	27.82	49.10	5.38	17.70
200403a	-0.12	1.62	0.72	1.92	-0.88	40.20	30.90	5.38	23.52
200601a	1.32	0.77	-0.38	2.72	1.42	0.00	33.16	48.44	18.40
200602a	0.63	1.26	0.32	1.56	0.15	3.05	57.61	16.07	23.27
200603a	-0.04	1.28	0.94	2.68	-0.49	18.63	59.75	6.86	14.76
210101a	1.36	0.80	-0.46	2.54	1.55	0.16	33.05	44.04	22.75
210102a	-0.16	1.19	1.58	3.98	-0.72	8.14	74.53	3.17	14.16
210103a	-0.81	0.38	-0.88	5.13	-0.75	22.52	77.48	0.00	0.00
210301a	0.57	1.08	0.32	1.99	0.29	3.16	61.32	23.03	12.49
210302a	-0.01	1.02	1.44	4.03	-0.45	4.49	79.64	5.33	10.54
210303a	0.29	1.36	0.64	1.84	-0.29	10.72	57.84	9.17	22.27
210401a	0.91	0.88	0.00	2.41	0.83	0.91	54.68	32.46	11.95
210402a	0.38	1.17	0.74	2.18	-0.17	3.71	68.09	10.84	17.36
210403a	-0.98	1.76	0.62	-0.14	-1.76	71.49	7.86	3.48	17.17
210601a	0.83	0.96	0.12	2.11	0.73	0.91	57.00	29.09	13.00
210602a	0.71	1.16	0.18	1.73	0.39	3.15	56.65	19.96	20.24
210603a	0.09	1.47	0.66	1.87	-0.66	25.22	44.42	8.84	21.52
220101a	0.86	0.87	0.12	2.40	0.73	1.27	58.35	29.17	11.21
220102a	-0.37	0.98	2.36	7.69	-0.74	7.91	82.01	2.20	7.88
220103a	0.16	1.31	0.58	2.00	-0.28	19.15	52.30	13.87	14.68
220301a	0.58	1.02	0.40	2.10	0.30	1.80	64.80	21.68	11.72
220302a	0.48	1.22	0.70	1.91	-0.25	1.01	67.49	9.25	22.25
220303a	-0.32	1.22	1.12	3.31	-0.73	32.72	47.44	7.54	12.30
220401a	0.67	0.71	0.44	2.84	0.54	0.27	71.16	24.61	3.96
220402a	0.80	1.29	0.14	1.44	0.27	2.72	52.99	14.13	30.16
220403a	0.26	1.59	0.28	1.56	-0.25	30.50	32.71	11.50	25.29
220601a	0.89	0.92	0.10	2.24	0.81	0.65	55.39	31.28	12.68
220602a	0.84	1.26	0.08	1.50	0.52	2.65	51.46	17.86	28.09
220603a	0.55	1.07	0.38	2.06	0.23	3.66	63.45	19.50	13.39

(Sheet 3 of 3)

3 Beach Profile Dynamics

Time sequence analysis of profile lines showed that the foreshore systematically decreased in elevation from the first day (12 October) to the fifth day (16 October) of the experiment. This is termed the erosional sequence since sand on the lower foreshore was removed from this area, creating a net deficit along the foreshore portion of the profile. From day 5 (16 October) to day 11 (22 October) all foreshore profiles exhibited a gain in elevation. This 6-day period is termed the accretionary sequence since the lower foreshore systematically gained sediment on each successive day, resulting in net accretion in the study area.

Nearshore Wave Characteristics

Data from wave gage 191, located 0.8 km directly seaward of the study area in the 8-m water depth, was used to characterize the input wave data. Temporal variation in wave height (H_{mo}) and peak period (T_p) during the study are shown in Figure 3. The H_{mo} is an energy-based statistic equal to four times the standard deviation of the sea surface elevation and T_p is the wave period associated with the maximum energy density in the wave energy spectrum (Byrnes 1989). Two storm events were recorded from 9 October to 23 October bracketing the foreshore sediment and profile interaction study. The first storm event began on 10 October and reached a peak in wave activity on 11 October, the day before the start of this study. Wave heights greater than 2 m occurred until 2000 on 12 October (Byrnes 1989). The wave heights subsided to a minimum value on 15 October. The storm wave period increased as the storm moved through the area and long period swell characterized the wave record as the storm waned.

A period of relatively small waves (H_{mo} of 1 to 1.5 m) and short periods (T_p of 5 to 6 sec) occurred from 15 October to 18 October. The second storm event of less intensity (Byrnes 1989) occurred from 18 October to 20 October with wave heights greater than 2 m occurring for less than 24 hours. The wave periods increased at storm onset and continued as long period swell (T_p from 10 to 12 sec) past 23 October.

The erosional sequence as measured on the foreshore profiles, occurred as the first storm was waning and the wave heights were decreasing. The periods remained long until 15 October. The nearshore rip channel formed during this period. The transition from erosion to accretion on the 17th, came after two days of relatively small waves with short periods. The rapid rise in wave height and an increase in wave period characterized the onset of the second storm event. The foreshore response was surprisingly, one of accretion. This accretion continued as wave heights

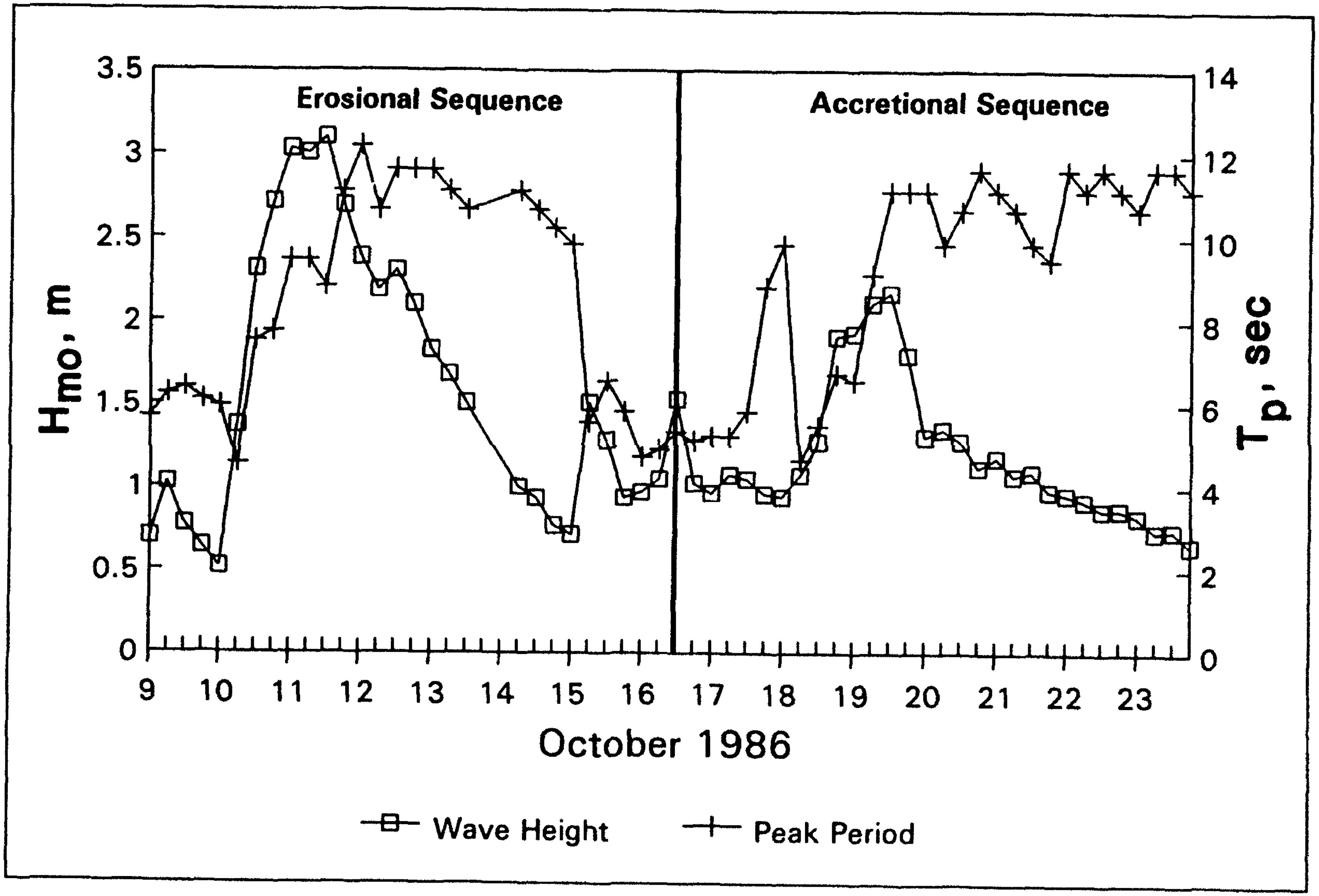


Figure 3. Plot of root mean wave height and peak period measured at 0.8 km seaward of foreshore study area in 8-m water depth at gage 191 (after Byrnes 1989)

decreased after the 20th. Peak periods continued to be long as wave heights decreased. Nearshore bathymetry during this time was characterized by southward and then landward migration of the offshore bar.

Foreshore Profile Changes

Foreshore profile data were collected daily along the six transects. Analysis of profile change along lines 1, 3, 4, and 6 will be discussed. Profile lines 2 and 5 are not included in the analysis since sediment data collected along these lines has not been analyzed. Measurements were taken from the toe of the dune, across the berm and foreshore to the lower limit of the swash zone. These areas of the subaerial beach experienced change on a daily basis due to swash and backwash interaction with foreshore sand deposits.

Erosional Sequence

Figure 4 shows the measured changes in elevation along the study profiles. Profile #1, the southern most profile in the study area, had the lowest elevation overall compared to the other three profiles. For profile #1, the erosional sequence is characterized by daily erosion on the middle to lower foreshore between 92 and 113 m seaward of the FRF baseline. During the same time, deposition on the upper foreshore resulted in a distinctive berm crest, located at about 90 m on 16 October. However, this small amount of accretion was not enough to balance sand loss along the seaward portion of the transect. Foreshore profile shape changed from nearly planar to concave during this period.

Profile #3, located 15 m north of profile #1, had a more pronounced berm crest. Landward of the berm crest, there was little change, but on the lower foreshore the typical pattern seen during the experiment was visible. The lower foreshore elevation diminished as the sand eroded from this position. Profile shape changed from one of concave to one of convex in the lower foreshore. The berm remained stationary at about 84 m from the backshore reference position.

Profile #4 was located 7 m north of profile #3. Since these two profiles are in close proximity to each other, their pattern of change occurred in a similar manner. Aside from some accretion in the upper foreshore just below the berm crest between the 12th and 13th, this profile experienced daily erosion across the foreshore. The berm crest maintained itself between 84 m and 86 m seaward of the backshore reference position. Shape changed from convex to concave as the foreshore eroded.

Profile #6 was located some 20 m north of profile #4 and was the northern most profile in the study area. This profile had a berm crest around 87 m from the backshore reference point that remained constant over the erosional phase. Profile 6 had a higher elevation overall than profiles to the south. The lower foreshore experienced larger erosion with an envelope of change of about 0.8 m during the erosional sequence. The profile shape went from convex to concave as erosion progressed.

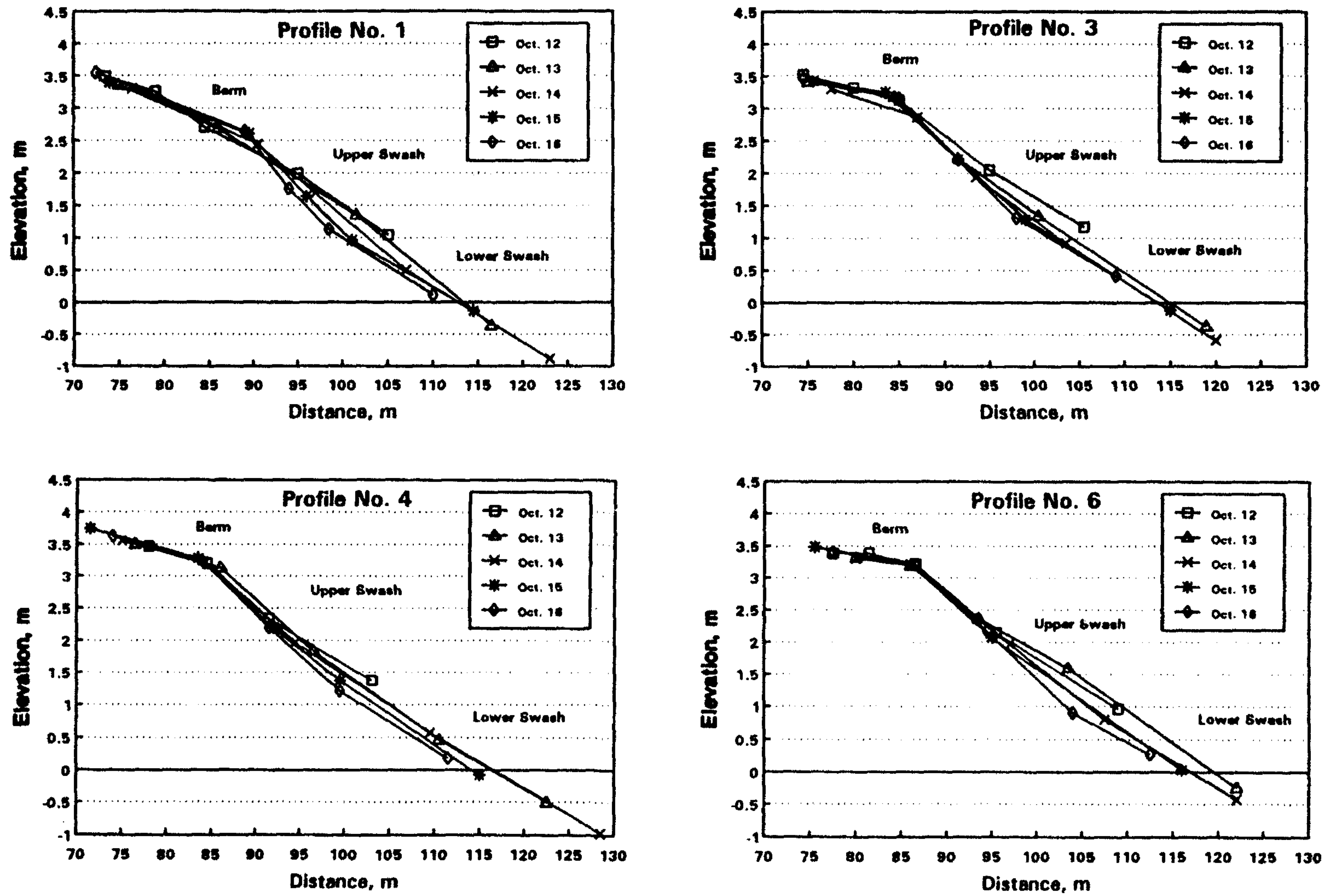


Figure 4. Foreshore cross-shore profile variation during the erosional sequence

Accretional Sequence

During the accretionary phase from the 17th to the 22nd, the lower foreshore on profile #1 gained sediment on a daily basis (Figure 5). The profile shape changed from concave back to planar in shape as the berm retreated landward and became indistinguishable by the 22nd. A nodal point can clearly be seen at 92 m where the level of the beach remains constant as the sediment alternately erodes and accreats around that point.

On profile #3, the lower foreshore gained sand from the lowest profile on the 17th to the highest profile on the 21st. Profile shape changed from concave to planar and the berm crest moved 2 m landward as the upper foreshore and berm accreated. Most accretion occurred between the 18th and 20th. A nodal point occurred at 87 m on this profile throughout the study period.

The accretion sequence at profile #4 was evident with the gain in the foreshore area from around 90 m on the mid-foreshore to the lower swash. Most accretion occurred between the 18th and 20th of October. The nodal point is observed around 87 m as the profile shape changed from concave to planar. A berm crest was observed to remain stationary around 83 m, with little change in elevation on the upper foreshore over this period.

Accretion can be observed on profile #6 from the 17th through the 22nd. All of the accretion was on the mid- to lower foreshore area seaward of 92 m. During the accretional period the level of sand returned to the profile was about equal to that lost during the erosional sequence. The berm crest remained fix at around 86 m seaward of the baseline, with virtually no change in berm elevation over the study period.

Cumulative Volume Change

Cumulative volume change from the four foreshore profile lines, between their origin around 70 m seaward of the FRF baseline and 116 m (the shortest profile) showed that there was a general trend of erosion on the foreshore during the first five days of the experiment (12 to 16 October) as seen in Figure 6. While there were minor differences in volume changes on any given day, all profiles showed a similar trend, with the foreshore losing between 10 and 16 m^3/m of sand by 16 October. Profiles 3 and 6 exhibited the greatest variability in erosion rates, while profiles 1 and 4 measured a steady rate of about 2 m^3/m erosion per day.

Between 16 and 17 October, the erosion trend reversed with accretion of sand on the foreshore on all profiles until 20 October. Profiles 3 and 6 exhibited slight erosion between 21 and 22 October while profile 1 continued to gain sand and profile 4 showed no significant change.

Profile 1 showed the most variability, with a rapid gain in foreshore sand volume between 16 and 17 October, and a slower increase between 17 and 22 October. On the other hand, profile 4 exhibited net sand accretion from 17 to 19 October and then remained relatively constant through 21 October. The volume of sand on the foreshore went through a cycle of erosion and accretion where the volume of sand at the end of the sampling period was equal to or slightly less than at the beginning of the 11-day study.

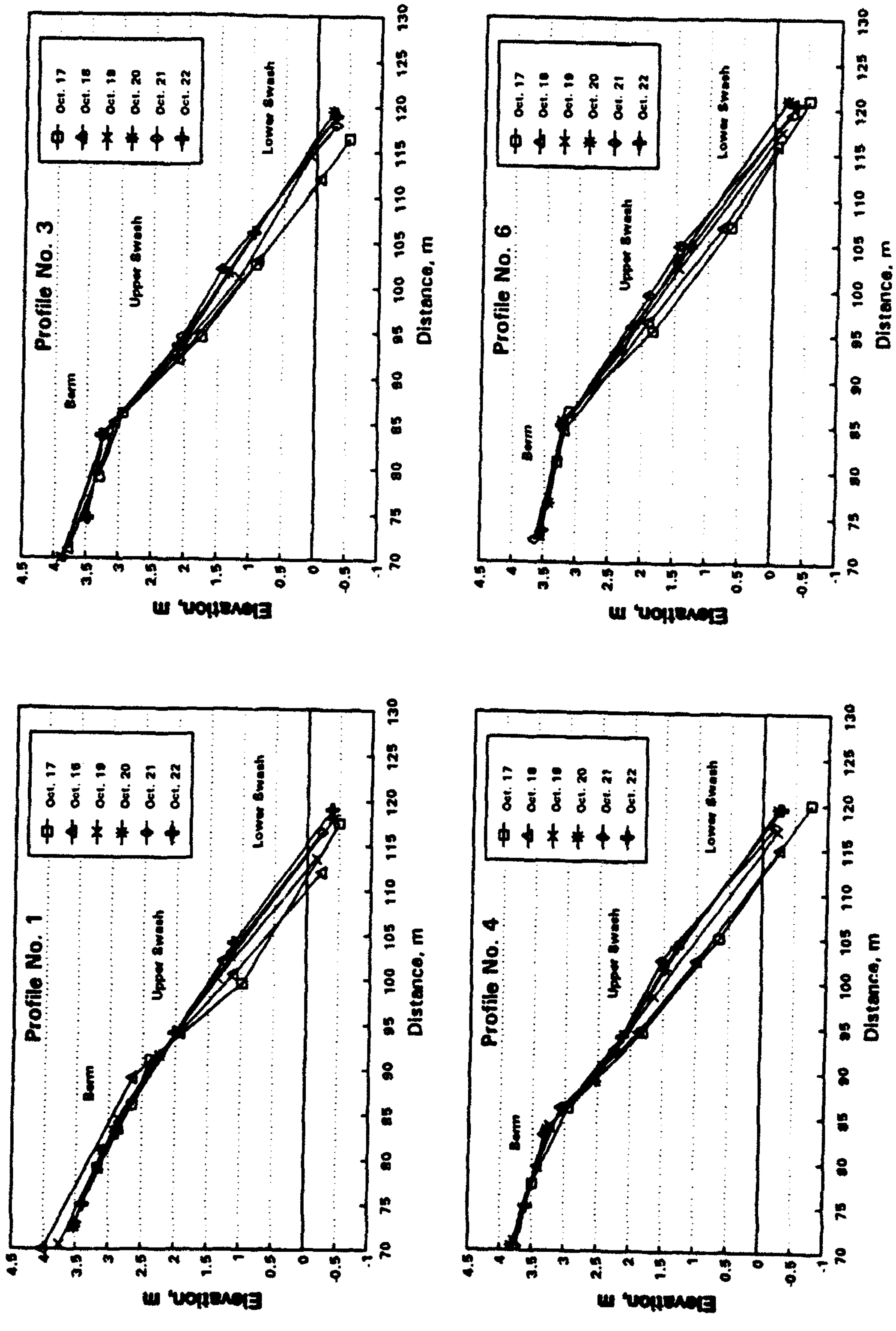


Figure 5. Foreshore cross-shore profile variation during the accretional sequence

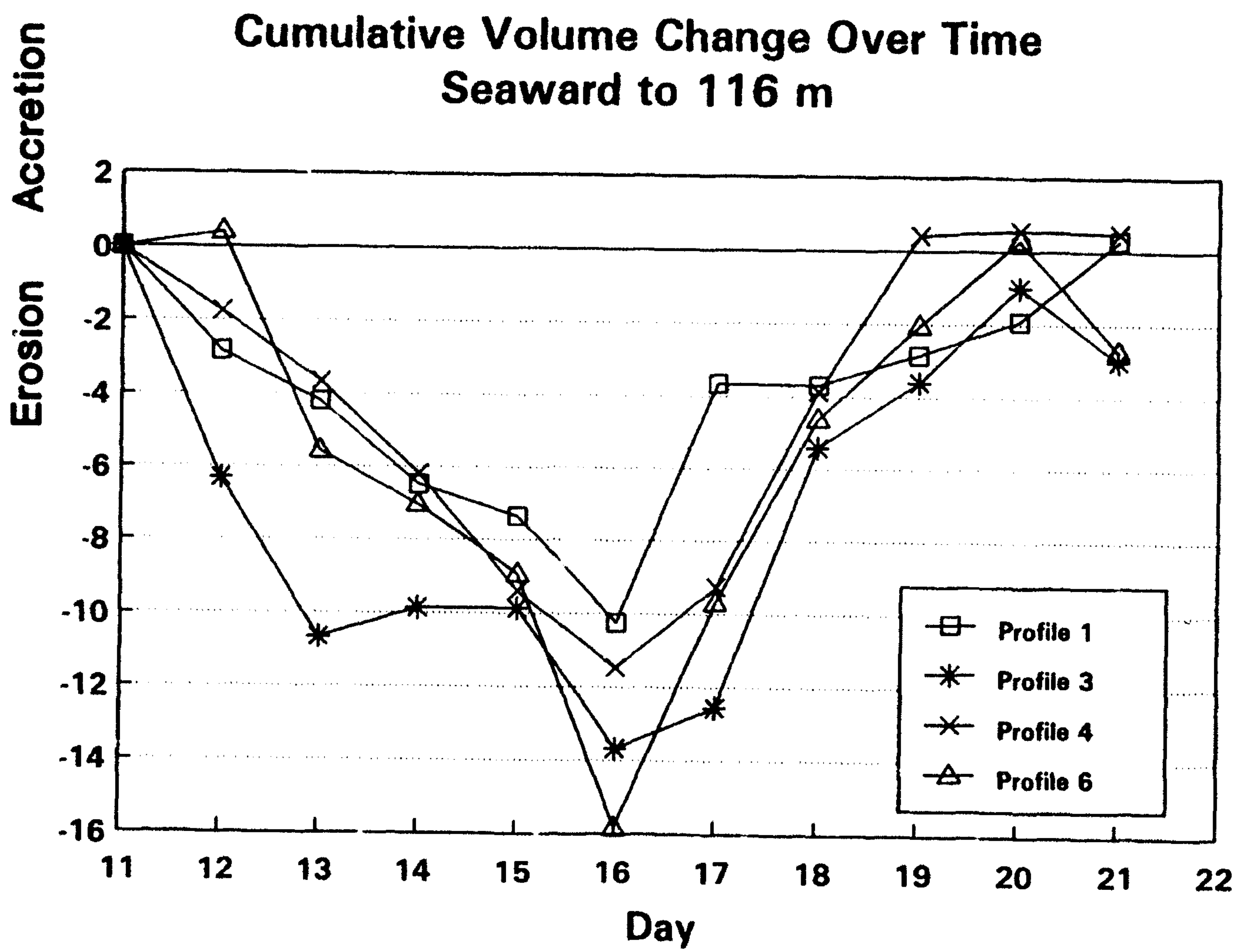


Figure 6. Cumulative volume change on the four foreshore profiles during the 11-day experimental period

Nearshore Profile Changes

FRF personnel collected profile data with the CRAB on an almost daily basis from the toe of the dune seaward past the nearshore bar during the experiment. Data were reduced and supplied by William Birkemeier of the FRF. Two of the long profiles, lines 235 and 240, correspond to the foreshore profile line numbers 4 and 1, respectively. These nearshore profiles extended to a maximum offshore distance of 366 m (1200 ft). The bathymetric survey area extended from profile 275 which was about 185 m (607 ft) south to profile line 165 which was 360 m (1181 ft) north of the foreshore study area. Bathymetric maps were constructed from the profile data on a almost daily basis during the study. A time series of three-dimensional plots of the bathymetric survey data grid are presented in Byrnes (1989).

An examination the nearshore bathymetry maps showed that on 12 October 1986 the offshore bar was located approximately 185 m (600 ft) seaward of the FRF baseline in front of the foreshore study area (Figure 7). The bar crest elevation was measured around -1.4 m (-4.5 ft) below NGVD. The offshore bar feature began just south of the foreshore study area and extended alongshore continuously for 300 m (984 ft) to the northern limits of the survey. From 13 October to 16 October (the erosional sequence on the foreshore) the bar feature progressively dissipated in front of the study area. The bar form was present at the southern most end of the survey limits and some 100 m (328 ft) to the north as a trough developed off the study area on 13 October. This alongshore trough was around 150 m (492 ft) wide. In front of the study area, the trough became normal to the beach as a rip current channel formed. By 14 October, the offshore bar and trough feature was completely erased and a planar offshore slope formed normal to shore within the rip channel. This channel maintained its position at a depth of 2.3 m (7.5 ft) until 15 October. Figure 8 shows in profile view the change at profile 240 for this erosional sequence. The bar feature on the 12 October profile survey was lowered as the trough filled forming a planar nearshore by 16 October.

By 16 October the rip channel began to shoal and the alongshore bar feature began to redevelop in the nearshore in front of the study area. From 16 October nearshore profiles were taken on every other day until the end of the experiment. The accretional sequence on the foreshore began on 17 October as the lower foreshore began to accrete. The nearshore profile plan view (Figure 7) shows the nearshore bar form progressively migrating to the south from 16 October, reaching the study site on 18 October. The bar crest was at a minimum depth of -1.7 m (-5.5 ft) and was located at 177 m (580 ft) from the FRF baseline (Figure 8). By 20 October the bar had migrated south through the study area. The bar ended to the north of the study area at a new rip channel for the first time during the study period. By 22 October the bar had grown in height to its shallowest depth of -0.6 m (-2.2 ft) in front of the study beach and began to migrate onshore. This growth and landward migration of the nearshore bar corresponded with the accretion measured on the foreshore profiles during the accretional sequence of the study. This accretion occurred during the second storm event between 18 and 20 October.

The complex three-dimensional response of the nearshore was a result of rip channel development in the circulation pattern. This resulted in the local offshore bar lowering during the erosional foreshore sequence. As the rip channel migrated with the longshore current, the bar feature reformed in front of the study area during the accretional foreshore sequence. Another rip channel appeared to form in the northern portion of the survey area at that time. The interaction of the onshore/offshore circulation and bar movement in relation to the longshore

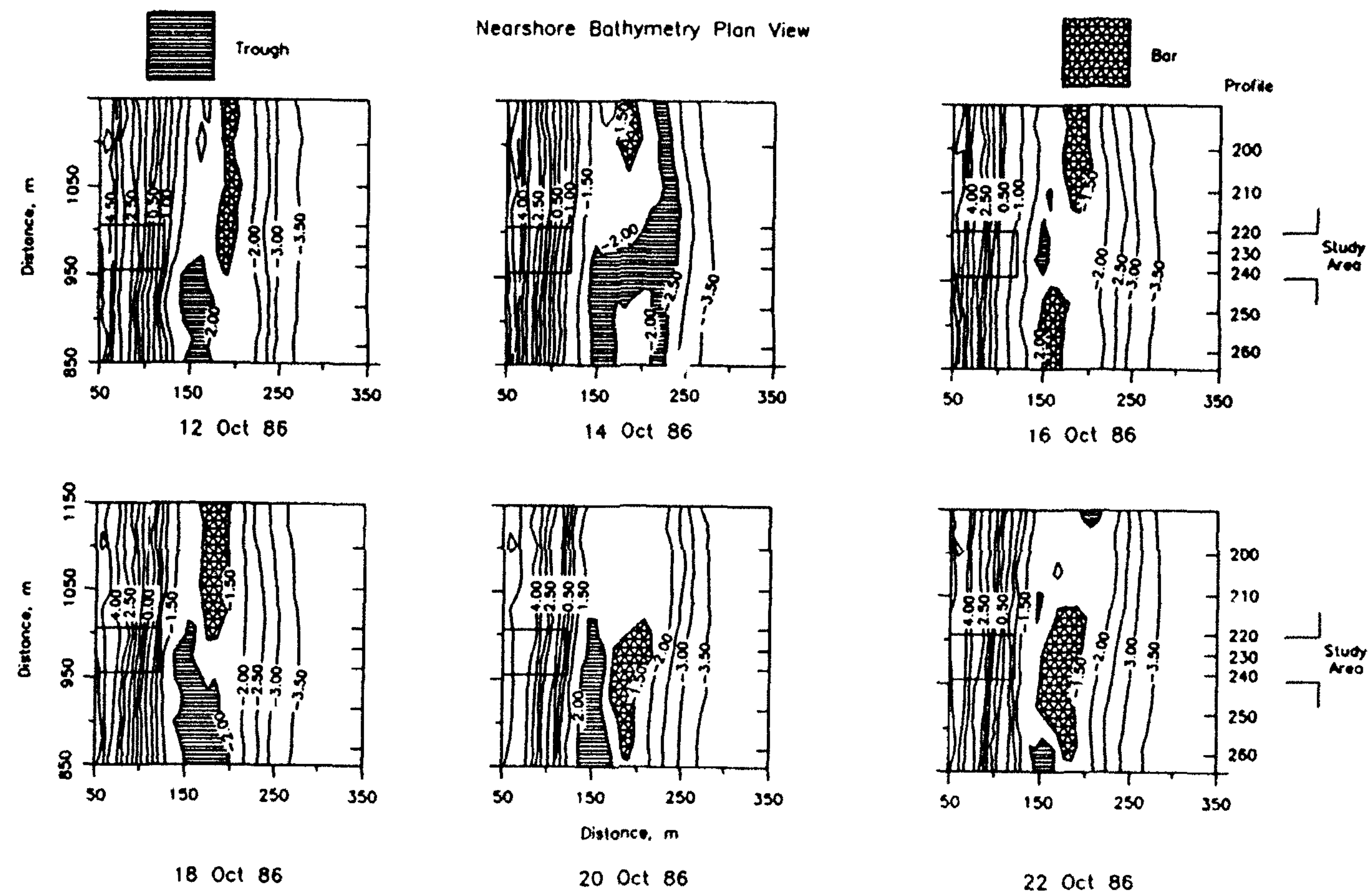
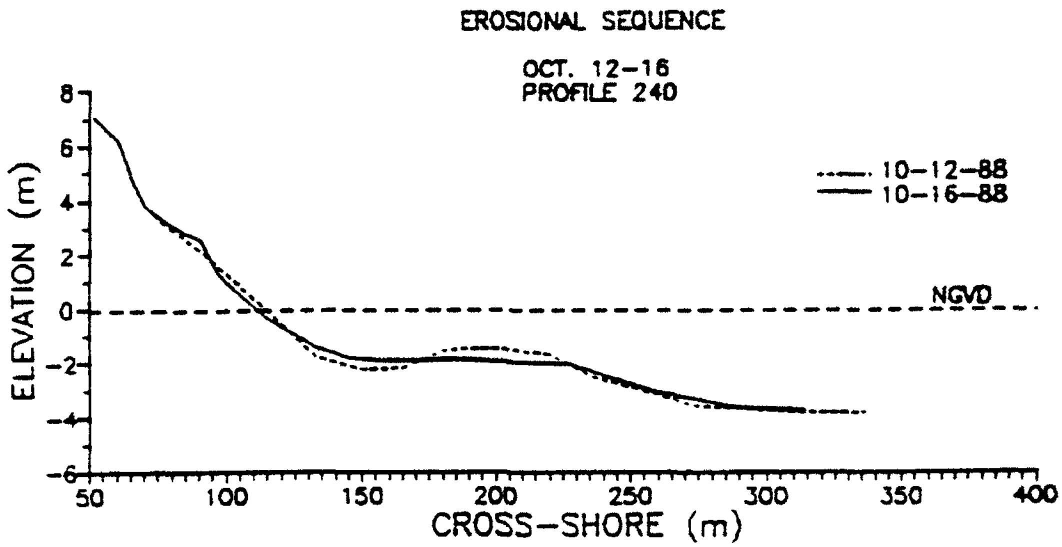


Figure 7. Plan view of the nearshore bathymetry showing variation in nearshore bar and trough position during the erosional (top) and accretional (bottom) foreshore profile sequences (the box identifies the foreshore study area)



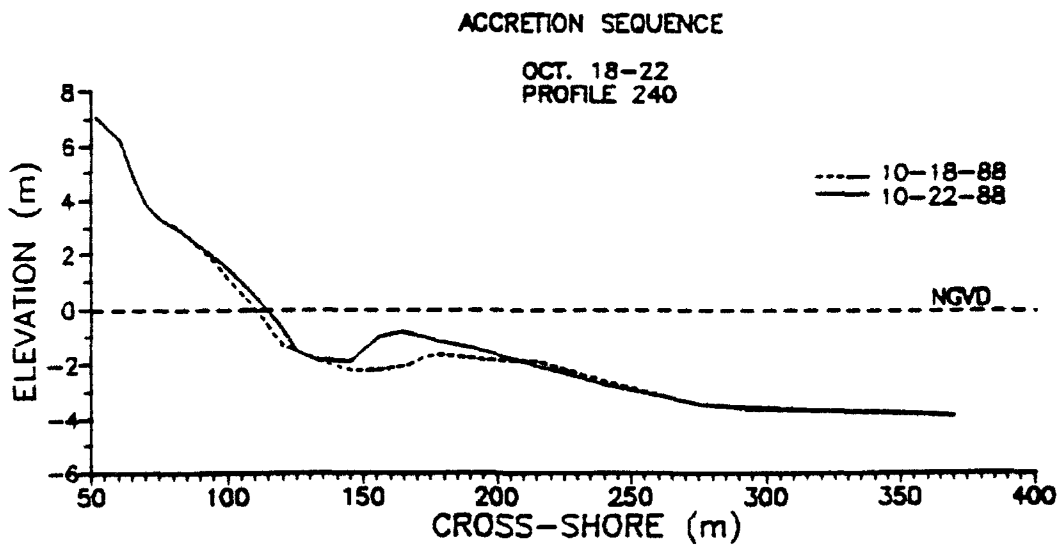


Figure 8. Nearshore profile line 240 showing the removal of the nearshore bar during the erosional sequence and the landward migration of the bar during the accretional sequence

movement of the rip channel in the direction of the longshore current appears to effect the foreshore erosion/accretion pattern.

4 Foreshore Sediment Dynamics

Sediment Distribution Classification

Short cores were obtained at locations within the berm, upper swash, and lower swash morphologic zones. These zones represent morphodynamic divisions in the swash/backwash process on a ocean beach foreshore. The lower swash zone corresponds to the region near mean low water where the interaction of the swash and backwash is most intense. The dynamic interaction between backwash and incoming surf is described by Bruninkmeyer et al. (1977) and often results in coarse sand deposits in this turbulent energy interaction zone. The frequency of interaction between backwash and incoming surf plays an important role in sediment deposition on the lower foreshore. During storm conditions, the interaction between incoming waves and resulting backwash can create increased erosive conditions. Groundwater also plays an important role in swash deposition processes (Pollock and Hummon 1971; Wadell 1976). Conditions of supersaturation almost always exist in the lower foreshore. This supersaturation condition increases pore pressures and allows for easier entrainment of sand. Sand was found to move down slope as bedload in the lower foreshore (Wadell 1976). No ground water data was collected during this study.

The upper swash zone is located on the upper foreshore, where groundwater fluctuates as a function of tide level, creating a periodically saturated zone. During conditions of non-saturation, which occurs during the low water phase of a normal tidal cycle, infiltration of the incoming swash can create a condition favorable to local deposition (Wadell 1976). As the tide rises, this zone becomes saturated and at higher water phases of the tide, erosion of material in this zone may occur. After reviewing large data sets of cross-shore sediment variability from many beaches Bascom (1959) concluded that sediment deposited at mid-tide represents the best location to characterize the beach.

Berm samples were collected around the area of mean high tide near the local maximum runup line during storm conditions. This morphodynamic zone is almost always characterized by non-saturated conditions. During storm events, total water level is elevated and the berm becomes temporally submerged. During SUPERDUCK, berm samples were affected by elevated water level on two days, when maximum runup over topped the berm. This backshore area is commonly a zone of under-saturation, which often allows rapid infiltration of swash into the beach. Wadell (1976) found that sand transport exists as highly turbulent suspended load at the leading edge of the swash bore, until upslope momentum slows near the position of maximum uprush. Deposition of this suspended material occurs rapidly before gravity initiates the backwash motion (Wadell 1976, Stauble 1978).

A review of the sand grain size data for samples collected in the study area illustrated high variability between individual samples, however spatial or temporal trends in medial grin size were apparent (Byrnes 1989). This report provides a more detailed examination of trends by attempting to classify size distribution for the entire data set. A total of twelve size distributions were identified based on the percentage of sediment contained in the gravel, coarse, medium, and fine sand sizes (Folk 1980) and the shape of the frequency curve. Table 2 lists the criteria for classifying a given sample and the number of samples by morphologic zone in each category. Figure 9 shows an example frequency curve for each type of the sediment distribution. This classification ranges from samples that contain higher percentages of coarse material (Type 1) to samples that contain high percentages of finer material (Type 11). Type 12 samples contained greater than 30% of any three size classes, resulting in a poorly sorted sample with no dominance of any one grain size type.

Most of the samples on this beach are bi-modal, with two distinct peaks on the frequency curve. Only about 12 percent of the samples had a uni-modal distribution, all with a predominant peak in the medium sand size range, representing a near bell shaped curve common to many beach sand grain size distributions. The bi-modality,common with beach samples at the FRF, contains populations of predominantly coarse (gravel and coarse sand) and fine (medium and fine sand) material that represents mixing of fine nearshore sands with coarse beach sand and gravel.

Alongshore Sediment Variability

Spatial and temporal variation in grain size during the study period is illustrated by Figure 10. Swash processes are differentiated by the distribution of sediment types in each zone. The berm zone samples of profile lines 1, 3, 4, and 6 were most consistent. They show a slight spatial variability in sediment deposition in the alongshore direction with the southernmost berm sample exhibiting the most frequent variation. The predominant sediment types throughout the study period were types 5 and 6 (coarse, and coarse to medium sand). This zone is characterized by deposition of uprush transported sediment by percolation of a high percentage of swash fluid into an under-saturated beach, conditions that were similar along the study area. The elevation of the berm was unchanged during most of the study period (Figures 4 and 5). since the berm area was only affected by maximum uprush at high tide during most of the experiment, Swash processes did impact this morphologic zone only on two days, when the swash overtopped the berm crest. (Elevation changes were measured on profiles 1 and 3 on the 21 and 22 October).

The upper swash zone samples showed the highest variability in sediment types, both temporally and spatially (Figure 10). Since this is the area of the foreshore that has alternate uprush and backwash through much of the tidal cycle resulting in a fluctuating water table, this variation in size distribution is not surprising. A general temporal trend can be identified with finer sediment types and higher alongshore variability progressing from the beginning, to the middle of the study period (during the transition from the erosional to accretional sequence). The most frequently occurring sediment type throughout the study was type 5 (coarse sand). Except for a few samples, the upper swash zone became more consistent during the accretional sequence.

Lower swash sediment grain types were consistently coarser than upper swash and berm samples throughout the study period. A moderate amount of variability can be observed in

Table 2
Sediment Type Classification and Frequency of Type Occurrence of Each Sample

Type #		Classification	Frequency of Occurrence
1	GRAVEL	greater than 50% Gravel	5 lower swash samples
2	Gr-CS	greater than 50% Gravel, greater than 30% Coarse Sand	1 berm, 2 upper swash, 8 lower swash samples
3	Gr-FS	greater than 50% gravel, greater than 30% Fine Sand	1 lower swash sample
4	CS-Gr	greater than 50% Coarse Sand, greater than 30% Gravel	1 berm, 1 upper swash, 12 lower swash samples
5	C SAND	greater than 50% Coarse Sand	15 berm, 19 upper swash, 10 lower swash
6	CS-MS	greater than 50% Coarse Sand, greater than 30% Medium Sand	19 berm, 6 upper swash samples
7	CS-FS	greater than 50% Coarse Sand, greater than 30% Fine Sand	4 upper swash, 5 lower swash samples
8	MS-CS	greater than 50% Medium Sand, greater than 30% Coarse Sand	6 berm, 4 upper swash samples
9	MS-FS	greater than 50% Medium Sand, greater than 30% Fine Sand	1 berm, 2 upper swash samples
10	FS-CS	greater than 50% Fine Sand, greater than 30% Coarse Sand	1 upper swash sample
11	FS-MS	greater than 50% Fine Sand, greater than 30% Medium Sand	2 upper swash samples
12	3>30%	any three size classes greater than 30 %	2 upper swash samples

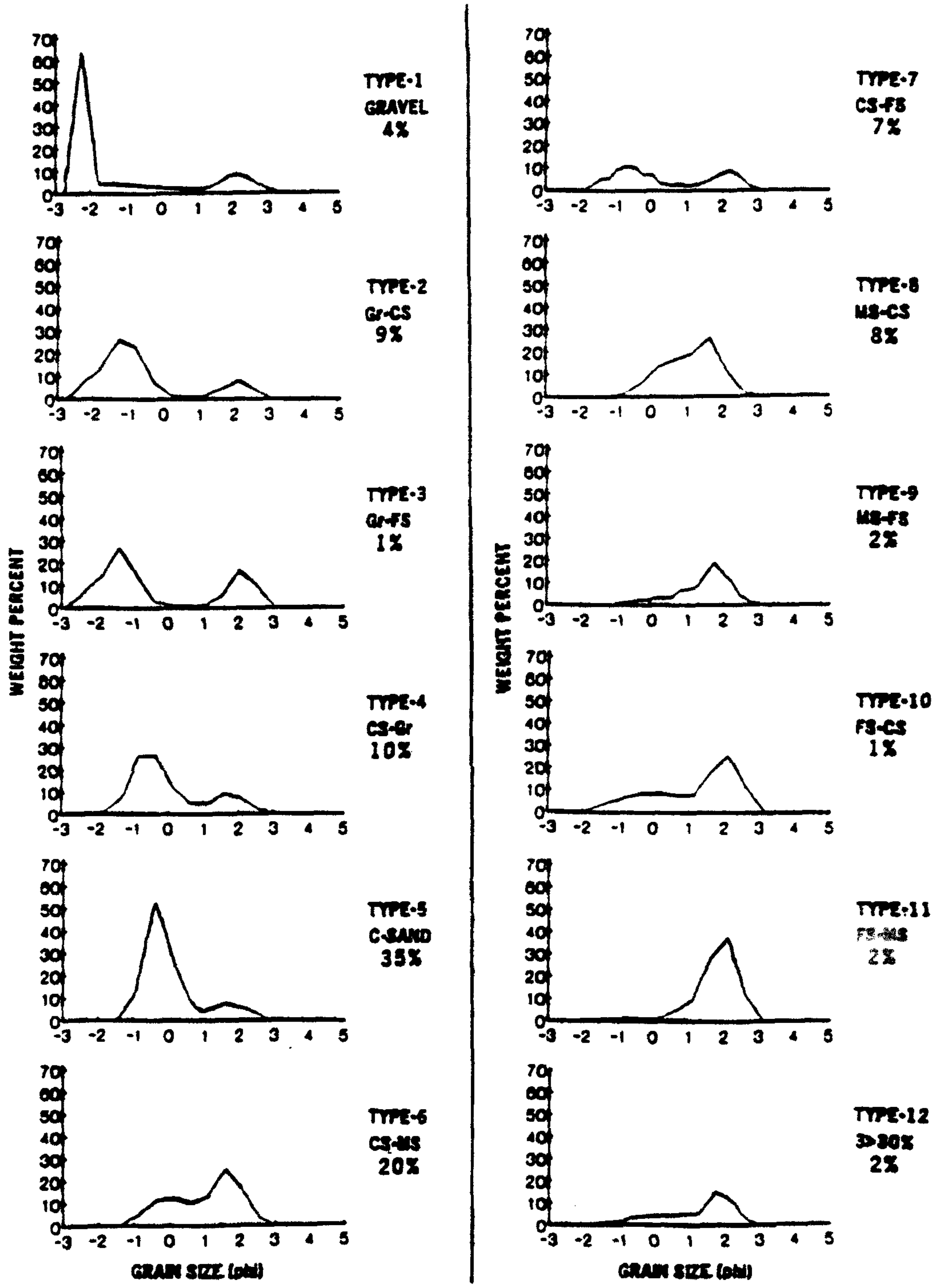


Figure 9. Frequency curves from the 12 sediment type classes identified based on percent of occurrence of size components (gravel, coarse, medium, and fine sand)

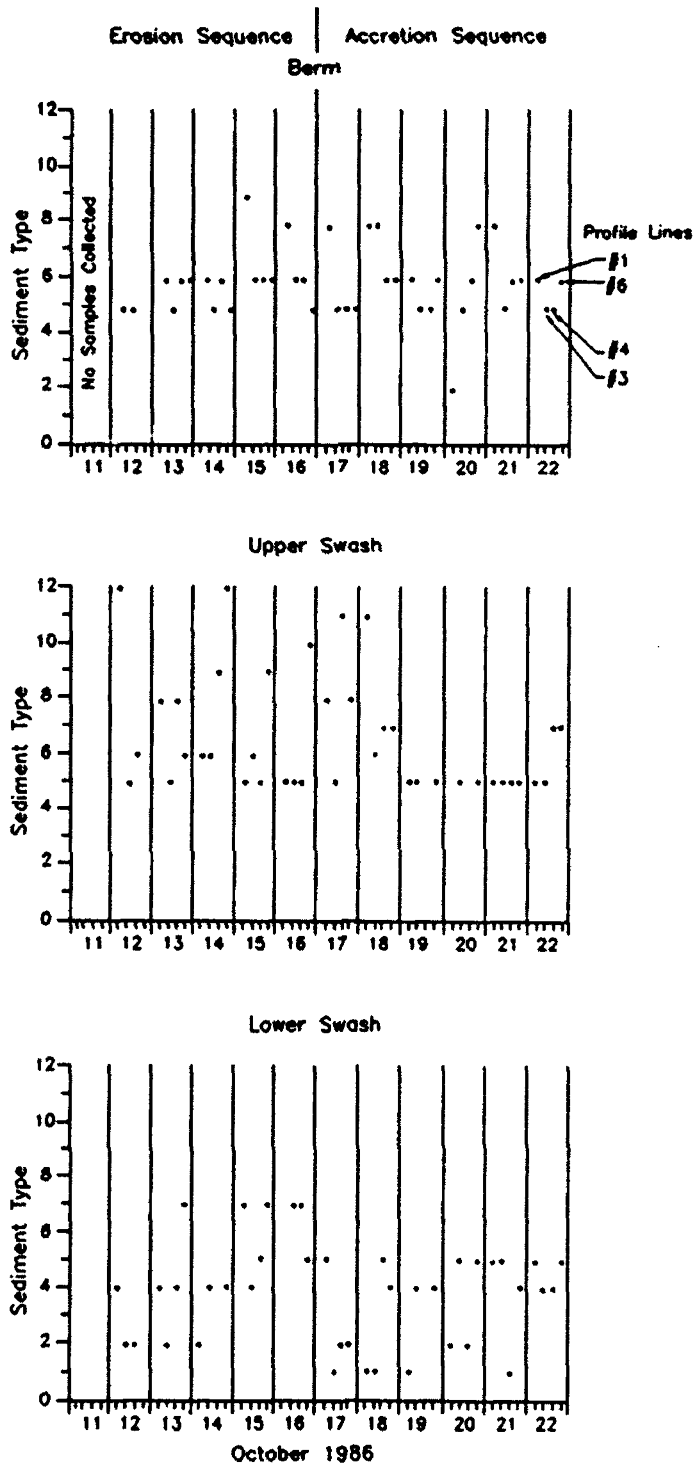


Figure 10. Alongshore variability in sediment grain size distribution types with the three sediment zones during the 11-day sampling

Figure 10 both temporally and spatially along the profiles. A general trend was evident of slight fining of this coarse material with alongshore variability progressing toward 17 October, the transition between the erosion and accretional sequence. This pattern was similar to upper swash sediment type changes. The lower foreshore zone is characterized as an area of turbulence from swash/backwash interaction which corresponds to the coarse nature of this sediment distribution. Higher alongshore variability in both spatial and temporal components occurred in the lower swash zone during the accretional sequence. Beginning on the 17th, a general coarsening occurred until the 22nd when there was a return to the most frequently occurring sediment types 4 and 5 (coarse sand and gravel, and coarse sand).

Cross-shore Sediment Variability

Cross-shore sediment grain size distributions exhibited a variability between the three foreshore morphologic zones. Profile 3 is used as an example of changes in sediment grain size during the erosional and accretional sequences. The cross-shore grain size variability is a function of the sediment transport processes of the uprush and backwash.

Erosional Sequence

During the erosional sequence, from 12 to 15 October, the lower swash samples along profile 3 contained a high percentage of coarse gravel size quartz material with a secondary mode of fine size quartz sand (Figure 11). On 16 October which was a transitional day between the storm events, the lower swash surface sample contained little gravel and more fine sand.

The upper swash grain size distribution showed the most variability during this erosional sequence. All of these samples were bi-modal in nature with a component of coarse sand and fine sand. Coarse sand predominated on the first two days of the study period with a shift to higher percentages of the fine sand component on the 14th and 15th. An exception occurred on the 16th when the grain size distribution was uni-modal with a strong peak in the coarse sand range.

Berm samples had grain size distributions similar to the upper swash samples during the erosional sequence. The berm samples however, shifted from a bi-modal distribution with a dominant peak in the coarse sand range to an even percentage in both coarse sand and fine sand size ranges on the 15th as the erosional sequence progressed. Foreshore grain size variation occurred while the foreshore profile was lowering in elevation and the offshore rip channel was forming in the nearshore area.

Accretional Sequence

As the accretional sequence began on the foreshore on 17 October, the lower foreshore sand distribution shifted back to a dominant gravel component while also containing a fine sand peak (Figure 12). The dominant coarse peak representing higher percentages of coarse gravel size material was best developed on the 18th. From the 19th to the 21st, the bi-modal distribution

EROSIONAL SEQUENCE

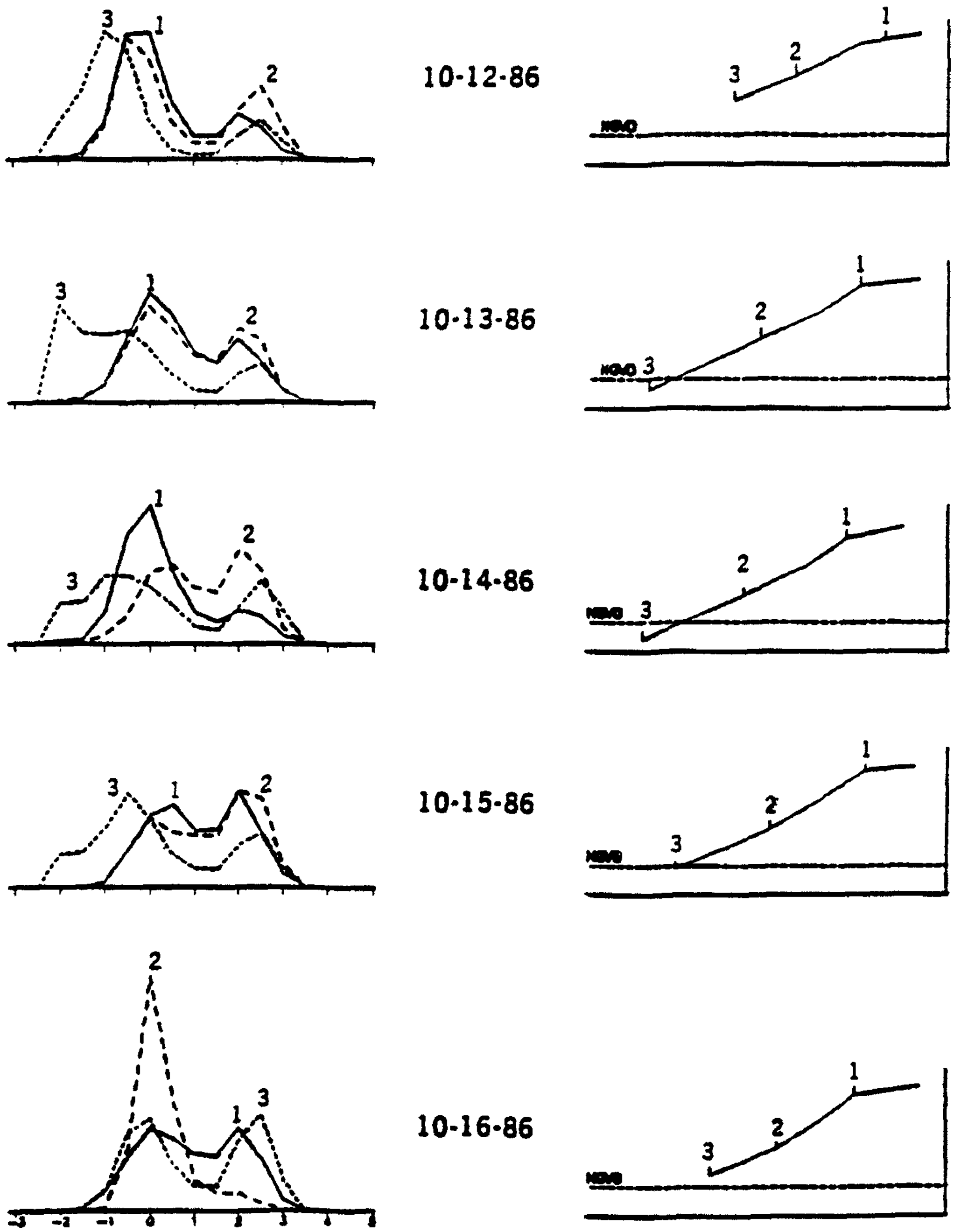


Figure 11. Berm (1), upper swash (2), and lower swash (3) sediment grain size distributions from profile line 3 and corresponding profile cross sections, showing changes in sediment composition by zone during the erosional sequence of the study

ACCRETIONAL SEQUENCE

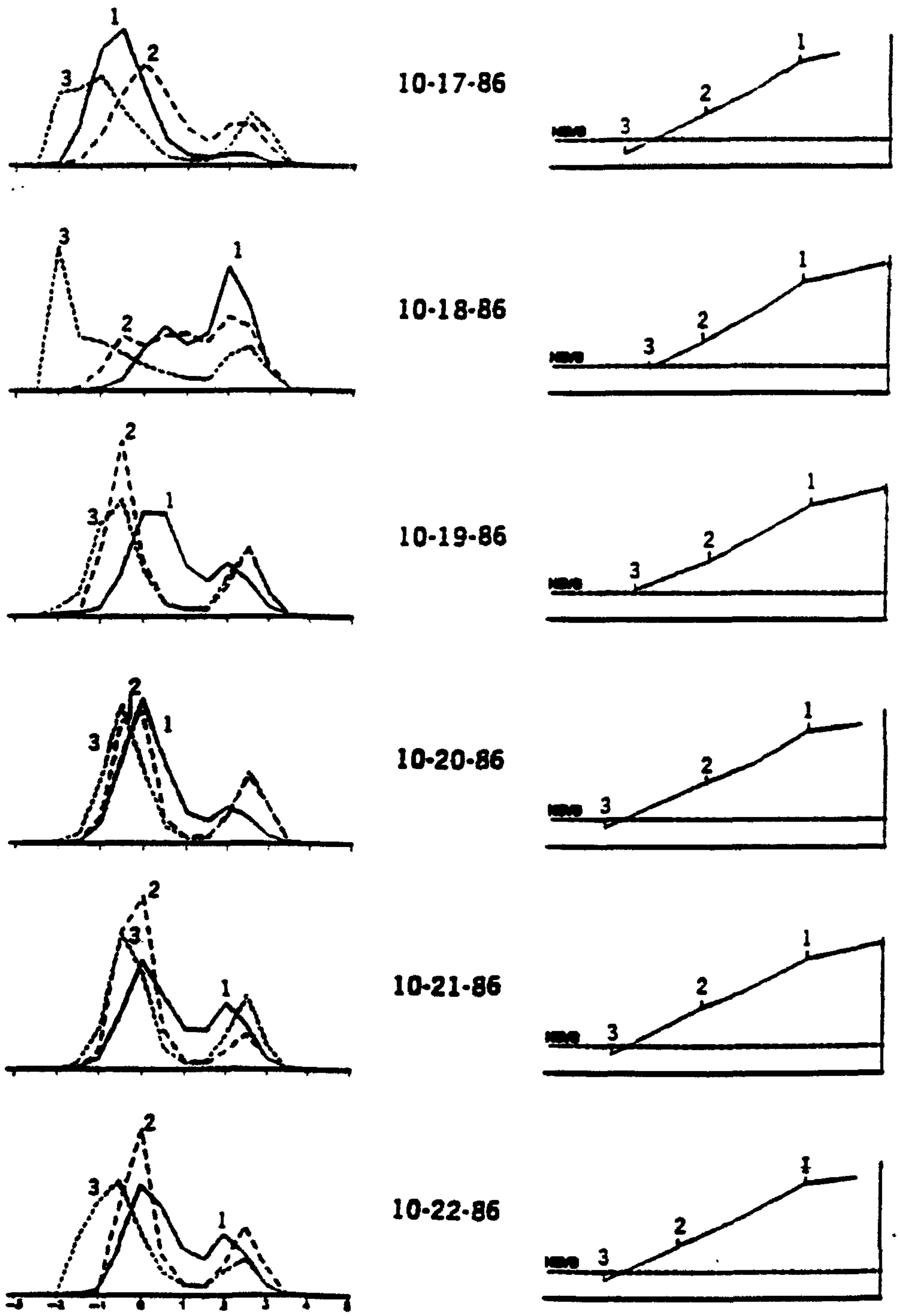


Figure 12. Berm (1), upper swash (2), and lower swash (3) sediment grain size distributions from profile line 3 and corresponding profile cross sections, showing changes in sediment composition by zone during the accretional sequence of the study

showed a slight shift to finer material, while still maintaining a dominance of coarser sands. More gravel size material returned to the lower foreshore on the 22nd, the last day of the study.

High variability was still present during the accretionary sequence on the upper swash area of profile 3. While mostly bi-modal in shape, finer material was present in high percentages at the beginning of the accretion period. Frequency curves showed an increase in dominance of the coarse sand mode as foreshore accretion progressed.

A fluctuation of dominant grain sizes was observed in the berm zone at the beginning of the accretion sequence. Finer material was missing on the 17th but became dominant on the 18th. A gradual shift back to coarser sizes in the principal mode occurred on the 19th and coarse sand remained the dominant size until the end of the study. Sediment variability decreased as the accretionary sequence continued, with a similar coarse sand peak distribution in all three zone samples from the 20th to the 22nd.

In order to interpret environments of deposition of the three cross-shore zones, an analysis was completed of the basic grain parameters of median and sorting. Size distribution of particles in a sediment sample will be influenced by the environment of deposition. By comparing median to sorting values of all surface sediment samples from all profiles in the three foreshore zones, the basic relationships of sediment deposition on the foreshore are evident. Figure 13 shows that finer median sands, that were also the best sorted, were predominantly located on the berm. Coarse median and poorly sorted material was characteristic of the high energy lower swash zone. The largest variability between median and sorting values were found in the upper swash zone, but a general trend in this widely scattered data showed that intermediate median grain size material with moderate sorting belonged to this group. Overlap between sediment statistical values from each zone indicated a merging of energy levels and sediment transport mechanisms as the swash and backwash move sediment on and off the foreshore. The more bi-modal the sample the poorer the sorting, as illustrated with the lower swash sands. These samples characteristically had a gravel or coarse sand component as well as a fine sand component.

A scatter plot of two process-sensitive statistical components, sorting and skewness, can show differences in deposition energies (Friedman and Sanders 1978). The sorting of a sample is dependent on the distance of transport, source, and amount of energy in the depositional environment, with well sorted beach sediments indicative of much reworking and winnowing out of non-equilibrium sizes. The more poorly the sample is sorted indicated a larger range of grain sizes. Skewness is a measure of the excess of fine material (positive skewness) or excess coarse (negative skewness) material in a grain size distribution. Figure 14 shows that despite some overlap, the berm and lower swash samples can be distinguished from each other. The berm showed better sorting and slightly negative skewness or a tail in the coarse range with a preponderance of finer material. The lower swash sands were poorer sorted with the two modes of gravel and fine sand. They also had slightly positive skewness or an excess of fine sand size material with a preponderance in the coarse sand size range. The upper swash fell in the middle, characterized by moderate sorting of coarse and medium sands and a wide range of skewness. Since this is the zone of both uprush and backwash sediment transport and deposition interaction with a fluctuating water table, alternate excess in fine and coarse sizes occurred.

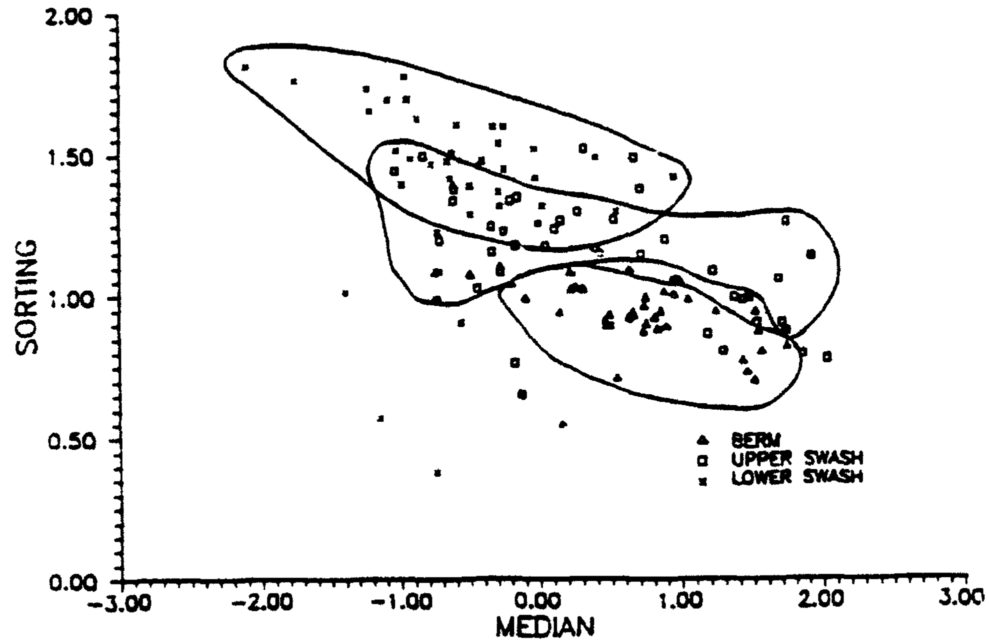


Figure 13. Plot of median versus sorting of sediment samples based on cross-shore zonation of berm, upper swash, and lower swash

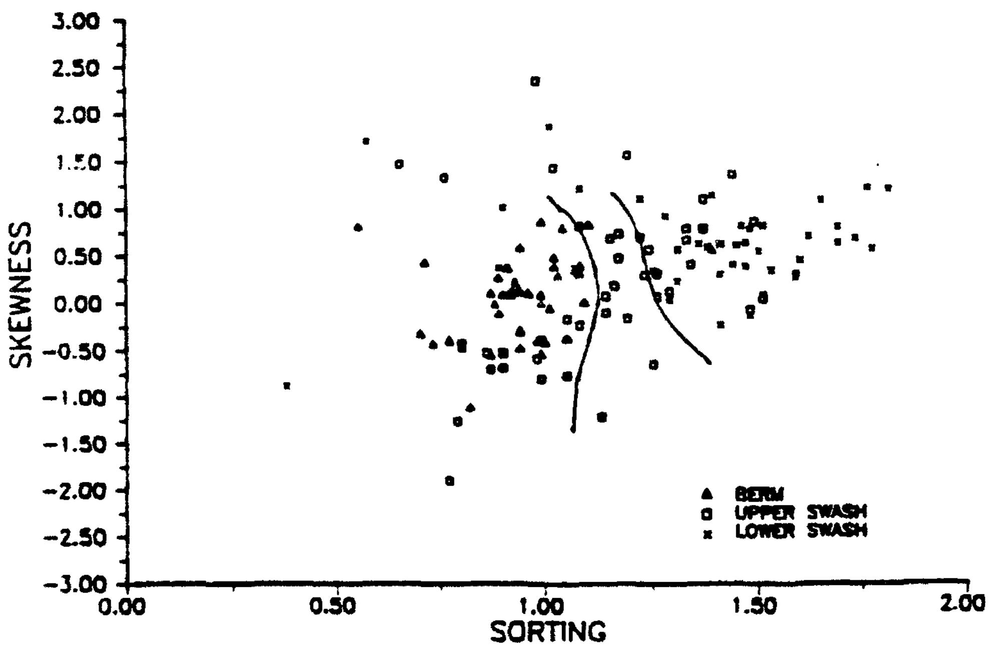


Figure 14. Plot of sorting versus skewness of sediment samples based on cross-shore zonation of berm, upper berm, upper swash, and lower swash

Composite Sediment Analysis

The high degree of variability in the grain size data of the individual surface sediment samples on both spatial and temporal scales presented difficulties in developing an interrelationship between the sediment compositional changes and profile response. A review of the sediment data indicated the majority of sediment samples were bi-modal. The usual practice of characterizing sands by their mean grain size did not give an accurate picture for samples containing two modes (especially ones that had their principal modes separated by several size classes). In this case the mean (average) value often occurred where there was a dearth in sediment by weight percent. A more accurate picture of predominant sediment grain size was given when the median (fifty percent value) was used (Byrnes 1989).

A comparison of the range in median values of individual surface sediment samples in the cross-shore and along-shore direction (Figure 15) showed there was more variability in the range of median values in the 50-m-wide cross-shore direction than in the 50-m-wide alongshore direction of the study area. The same basic swash processes and energy levels are present in the alongshore direction and the differences in grain distributions along this stretch of beach are on average less than one phi unit. Only on one day, 20 October, during the accretion sequence, did cross-shore variability in median values measure slightly less than alongshore variability. Four days during the experiment, the cross-shore variability was greater than two phi units in median value from the berm to the lower swash, indicating a large variation in the depositional processes across these zones.

In order to eliminate some variability and provide a clearer picture of sediment distribution on the foreshore, composite samples were mathematically constructed from the four alongshore samples in each zone on a given day using the techniques of Hobson (1977). Composite grain size distributions have been used in the past to average several grain size distributions into one composite for comparison with another individual or composite group of samples (e.g., Stauble et al. 1984). In this manner, variability and complex relationships can be simplified. Composite samples can be used for further analysis in the same manner as individual grain size distributions.

A daily composite was constructed from the four samples in each morphologic zone collected from profiles 1, 3, 4, and 6. A time history of the composite frequency curve is shown in Figure 16 for the 11-day study for the berm, upper swash, and lower swash. With some of the individual sample variability removed, a general trend in grain distributions between zones emerged. A time history of the berm composite showed the berm zone contained weakly bi-modal samples. The range in modes was narrow and occurred around the coarse sand to medium sand sizes. The predominant mode switched from the coarse to the fine component several times during the experiment and showed no strong trend with the erosion and accretion sequences. Percolation and deposition into the berm around the high tide area was somewhat independent of the storm processes, since there was no major inundation of the berm crest area and no swash penetration to the dune or reflection off a dune base. The basic normal swash processes of uprush to a maximum point, then deposition, immediately before the initiation of backwash occurred throughout the study.

Stronger evidence of the erosion and accretion sequence was observed in the time series of the upper swash composite (Figure 16). During the first few days of foreshore erosion the fine mode dominated a weak bi-modal distribution. The transition period from the end of the

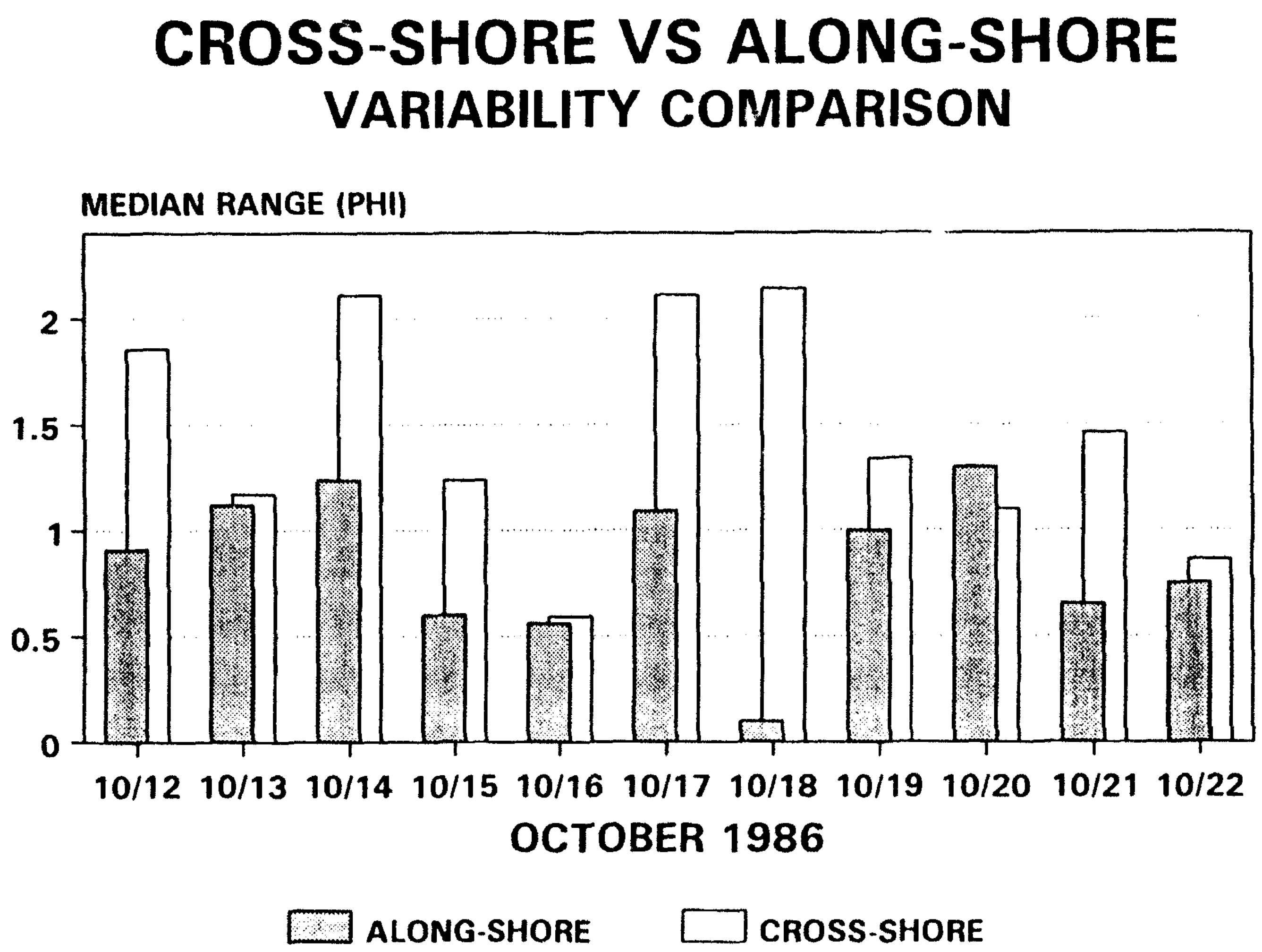


Figure 15. Cross-shore versus alongshore variability in median range of foreshore sediment samples

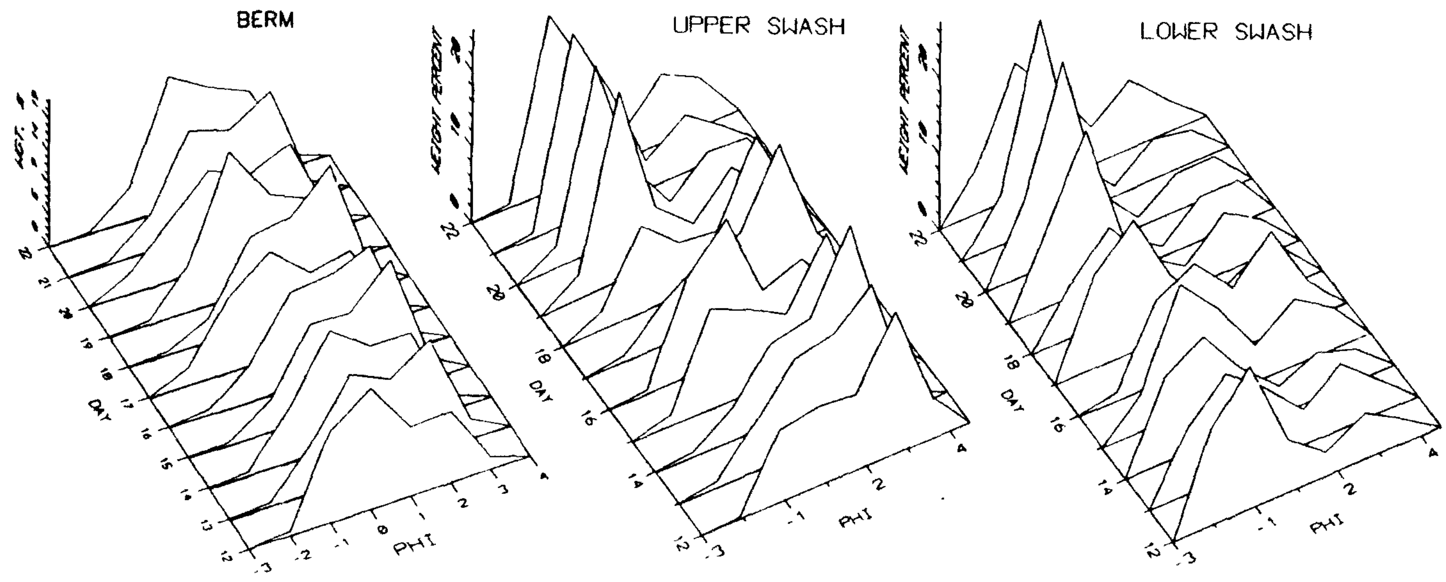


Figure 16. Composite grain size distributions for the three sediment depositional zones showing the daily changes and cross-shore variability in grain distributions for study period

erosional sequence to the beginning of the accretional sequence on the foreshore profile was characterized by a fluctuation from coarse to fine dominant peaks in the composite sediment distribution. The accretion sequence sediment distribution switched to a strong bi-modal spread in grain size, with a predominance of coarse material being deposited on the mid-foreshore.

The lower swash composite sample distribution exhibited a strong bi-modal shape throughout the entire study period. Although a shift to finer material occurred during the transition from erosion to accretion on the profiles on the 15th, 16th, and 18th, the lower swash became coarse during the accretional sequence similar to the upper swash.

A trend of general fining of the foreshore sediments during erosion of the foreshore was evident, particularly in the upper swash samples. An increase in coarse gravel and sand sizes is evident during the accretional sequence on the upper and lower swash. A distinct zonal response of sediment deposition to swash processes during the waning of one storm and the onset of another weaker one was observed as the foreshore first eroded, then accreted. To further characterize the change in sediment distribution, a grand composite was calculated, combining the grain size distribution data from all samples from all zones on a daily basis. This process simplifies analysis of changes in sediment distribution and provides statistical data averaged over the entire study area each day. Figure 17 illustrates the general trend in sediment size changes on a temporal basis. This summary data shows the bi-modal nature of the composite beach with two dominant peaks in the coarse sand and fine sand range. Of interest is how the relative percentages of these modes change due to swash dynamics during the study. A basic weak dominance in the finer peak is seen during foreshore erosion from 12 to 16 October. A switch to a dominance of the coarser mode is seen as accretion progresses during the second half of the study.

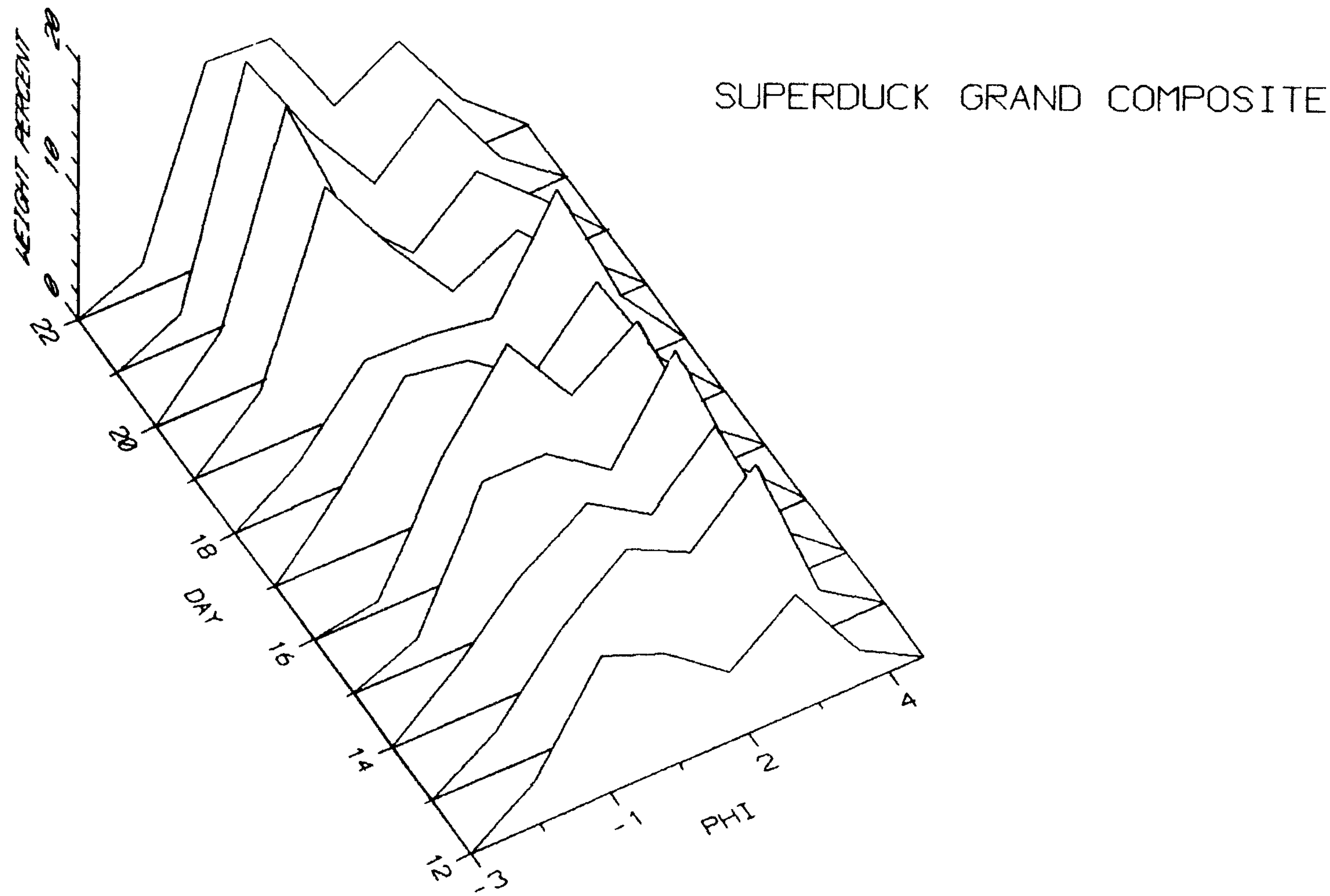


Figure 17. Plot of grand composite grain size distributions, created by averaging all sediments collected per day to illustrate general trends in sediment deposition in response to physical processes

5 Summary

The purpose of this experiment was to gather and analyze data on beach response to storm wave conditions. Data were collected during an eleven day experiment that was influenced by two extratropical storm events. Both daily nearshore and foreshore profiles were collected to give a three-dimensional picture of beach response. Surface sediment samples were collected to examine daily grain size distribution changes under the influence of storm swash activity. Near continuous wave data were collected from a wave gage located in close proximity to the study site in 8 m of water. This unique data set provided the opportunity to study detailed changes in the interaction of profile and sediment under storm conditions.

The wave gage record showed that as each storm approached the area, wave height increased. Wave periods were short during the storm but increased as the swell waves moved into the area from both of the departing low pressure systems. The wave height decreased rapidly as the first storm retreated. There was a period of variable, but for the most part, small waves with short periods between the two storms. The second storm saw an increase in wave height but for a shorter duration and with less intensity. The wave period remained long as the wave height decreased similar to the first storm.

Analysis of the four daily foreshore profiles showed there were subtle elevation changes in the alongshore direction but the main changes were in the cross-shore direction. The foreshore area exhibited progressive daily erosion during the first five days of the experiment as the first storm event waned. The last six days of the experiment showed a progressive accretion of sediment to the foreshore, even under the influence of the second storm. Elevation and volume of sand returned to almost the same level and magnitude as at the start of the study. This accretional sequence was initiated during a period of relative low wave activity after the first storm and continued during the onset of a less severe second storm event.

During the period of erosion on the foreshore, the nearshore profile was also changing. At the beginning of the study there was a typical shallow trough and offshore bar feature in the nearshore. As the first storm waned, a rip current channel developed normal to the beach and removed the offshore bar form immediately in front of the foreshore study area. As the second storm impacted the study area, a new offshore bar formed in front the study area, filling in the former rip channel. This bar continued to accreted and by the end of the study began to migrate onshore in the vicinity of the experiment area as the foreshore experienced progressive accretion. As the bar migrated onshore, a new rip channel formed to the north of

the study area. This localized cell circulation in the nearshore appears to effect both the nearshore and foreshore erosion/deposition patterns.

Sediments on the foreshore of the Field Research Facility beach exhibited a high degree of variability during the study period. Most of the samples showed characteristics of bi-modality, with a coarse sand and gravel component and a fine sand component. Samples were collected on a daily basis around the time of low tide in three zones in the cross-shore direction. Berm samples represented the area at or just above maximum runup or previous high tide. Upper swash samples were collected along the mid-tide area of the foreshore. Lower swash samples were collected in the low tide swash on the lower foreshore.

While there was some alongshore variability in the daily grain size distributions, the dominant differences in the components of each sample were in the cross-shore size distributions. From previous studies hydrodynamics of the swash uprush/backwash process and watertable interactions control the depositional pattern by zone. Cross-shore variability in this data set illustrated this relationship quite clearly. Most variability occurred in the upper swash zone samples on a daily basis. This zone was under the influence of both the uprush and backwash. The berm samples were for the most part finer and better sorted. These samples were deposited at the area of maximum uprush at the time that the swash bore velocity reached zero. Lower swash samples were consistently coarser and more poorly sorted than the other two zones. This area is under the influence of the interaction of the backwash with the incoming surf bore and is usually an area of turbulence, where only the coarse material can be deposited. The finer material will be kept in suspension and transported onto the foreshore by the swash or moves into the surf zone by the backwash.

To remove some variability in sediment grain size distribution data and to enhance trends in grain size distribution changes, composite samples were constructed within the three zones. A pattern emerged from the berm, upper and lower swash daily composite samples consistent with what is known about swash dynamics. A daily grand beach composite was constructed, which combined all zones into a single daily beach grain size distribution to further enhance trends and provide data to analyze the erosional and accretional sequences. The finer mode of the composite bi-modal distribution was dominant during the erosion sequence, while the coarser mode became more dominant during the accretional sequence.

An interesting pattern emerged from this study, suggesting that behavior of the foreshore beach was partially independent of the waves as measured in the intermediate water depth. Nearshore bathymetry appears to play a dominant role in the erosion and accretion pattern observed on the foreshore. No breaking wave data or nearshore circulation data were available in summary form to include in this report. Figure 18 summarizes the hypothesized interaction of coastal processes with the nearshore and foreshore response during the erosional and accretional sequences.

Development of the rip channel occurring with foreshore erosion indicates a coupling of cell type nearshore circulation with swash processes in seaward transport of sediment from both the foreshore and bar positions during the waning of the first storm. Waves break over the nearshore bar and dissipate much of their energy before traversing the trough area and finally breaking on the shore. The breakers in the vicinity of the rip channel break closer to shore and with more energy. With higher energy input, swash processes in front of the rip

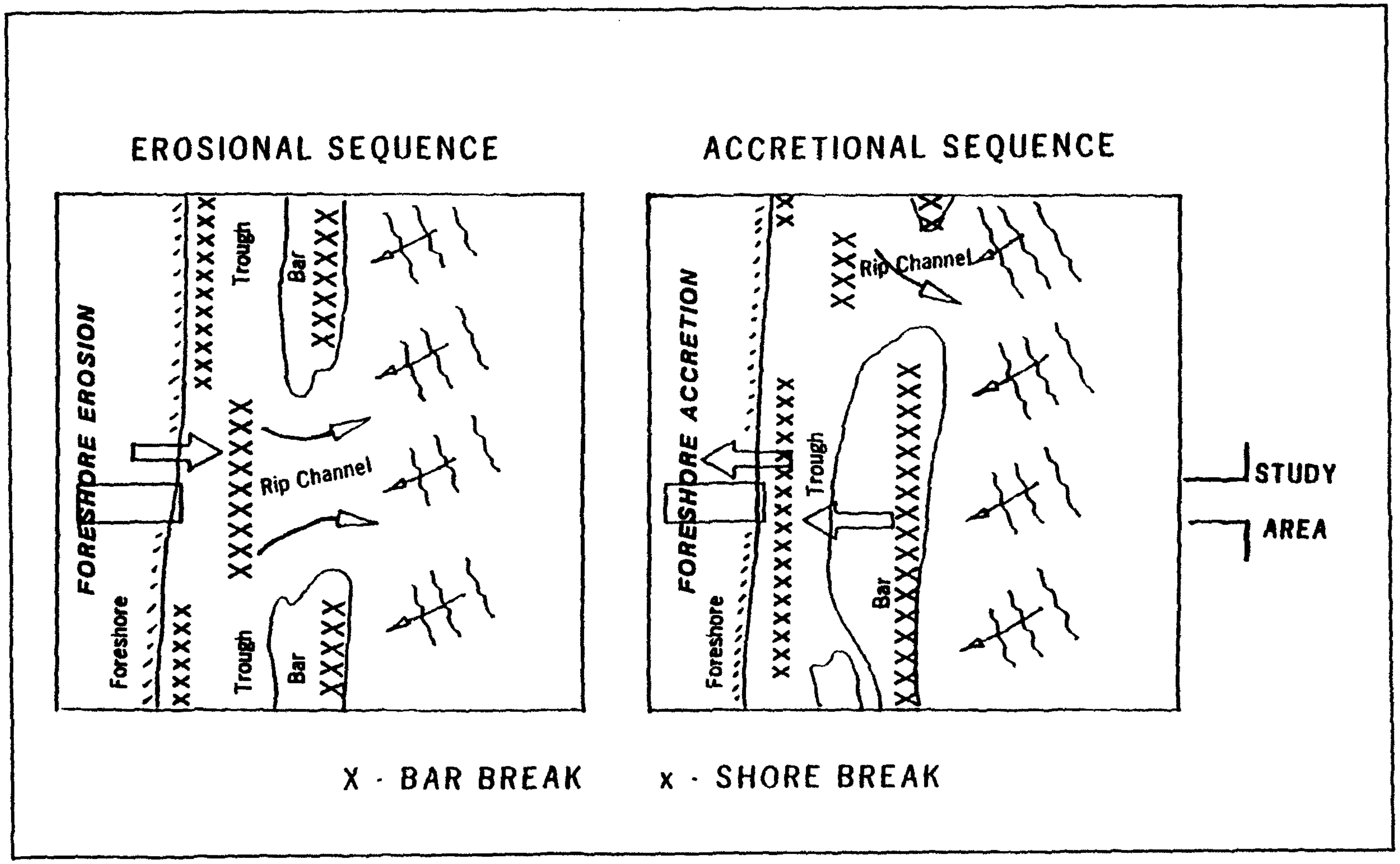


Figure 18. Hypothesized interaction between breakers, nearshore morphology and circulation, and foreshore response during the erosional and accretional sequences

channel presumably transported foreshore sediment seaward as the erosion sequence progressed. The general fining of foreshore sediments during the erosional sequence is not fully understood, but may be a result of swash/backwash interaction where coarser material was kept on the lower foreshore.

Southward drift of the nearshore bar occurred as the second storm moved from the area. This bar increased in area, with decreasing depth and shoreward migration at the same time as the foreshore experienced a progressive accretion. The switch from a seaward rip transport to a landward migration of sediment in both the nearshore and foreshore occurred as the second storm moved through the area. This coupling of accretional processes with wave climate at the end of the study needs to be further investigated. It can be speculated that wave input created a more longshore dominated nearshore circulation along the study beach. With accretion on the bar and landward transport of the bar feature, waves broke first over this bar dissipating their energy with landward transport of coarser sediment. Sediment was deposited on the foreshore by the lower energy shore break and swash processes.

Further research into interaction of sediment and profiles during erosional and accretional events is needed to understand the dynamic processes that interact on a daily basis on a natural beach. Variations in nearshore circulation, breaker types on both the bar and at the shore break and swash interaction all play a role with bar/berm morphology changes. Once our understanding of these processes are better defined, then we can proceed to design more efficient shore protection structures (such as beach fills) for eroding coasts.

References

Bascom, W. N. 1959. The Relationship Between Sand Size and Beach-Face Slope. American Geophysical Union Transactions, Vol 32, no 6, pp 886-874.

Birkemeier, W. A. and Mason, C. 1984. The CRAB: a Unique Nearshore Surveying Vehicle. *Journal of Surveying Engineering*, Vol 110, no 1, pp 1-7.

Birkemeier, W. A., Baron, C. F., Leffler, M. W., Hathaway, K. K., Miller, H. C., and Strider, J. B., Jr. 1989. SUPERDUCK Nearshore Processes Experiment Data Summary, CERC Field Research Facility. Miscellaneous Publication CERC-89-16, U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS.

Brenninkmeyer, B. N., James, C. P., and Wood, L. J. 1977. Bore-Bore Interaction on the Foreshore. *Proceedings of Coastal Sediments '77*, American Society of Civil Engineers, pp 622-638.

Byrnes, M. R. 1989. Superduck Beach Sediment Sampling Experiment, Report 1, Data Summary Report. Miscellaneous Publication CERC-89-18, U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS.

Crowson, R. A., Birkemeier, W. A., Klein, H.M., and Miller, H. C. 1989. SUPERDUCK Nearshore Processes Experiment: Summary of Studies, CERC Field Research Facility. Technical Report CERC-88-12, U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS.

Friedman, G. M. and Sanders, J. E. 1978. *Principals of Sedimentology*. John Wiley and Sons, New York, N.Y., pp 76-81.

Folk, R. L. 1980. *Petrology of Sedimentary Rocks*. Hemphill Publishing Company, Austin, TX.

Hobson, R. D. 1977. Review of Design Elements for Beach Fill Evaluation. Technical Publication 77-9, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Vicksburg, MS., 42 pp.

IAHR. 1989. List of Sea State Parameters. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, Vol 115, no 6, pp 793-808.

Pollock, L. W. and Hummon, W. D. 1971. Cyclic Changes in Interstitial Water Content, Atmospheric Exposure, and Temperature in a Marine Beach. *Limnology and Oceanography*, Vol 16, no 3, pp 552-535.

Stauble, D. K. 1978. The Interaction of Swash and Sediment on the Backshore in the Presence and Absence of Barriers. PhD. Dissertation, Univ. of Virginia, Dept. of Environmental Sci. Charlottesville, VA, 127 pp.

Stauble, D. K., Hansen, M., and Blake, W. 1984. An Assessment of Beach Nourishment Sediment Characteristics. *Proceedings of the 19th Coastal Engineering Conference*, American Society of Civil Engineers, Houston, Texas, pp 1471-1487.

Wadell, E. 1976. Swash-Groundwater-Beach Profile Interactions. In: R. A. Davis and R. L. Ethington (eds.), *Beach and Nearshore Sedimentation*, Society of Economic Paleontologists and Mineralogist, Special Publication No. 24, Tulsa, OK, pp 115-125.

Underwood, S. G. 1988. Sonic sifting: a fast and efficient method for sand size analysis. CETN II-4, U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
May 1993

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
SUPERDUCK Beach Sediment Sample Experiment:
Beach Profile Change and Foreshore Sediment Dynamics

5. FUNDING NUMBERS
WU 31665 and 32525

6. AUTHOR(S)
Donald K. Stauble, Garry W. Holem, Mark R. Byrnes,
Fred J. Anders, Edward Meisburger

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USAE Waterways Experiment Station, Coastal Engineering
Research Center, 3909 Halls Ferry Road, Vicksburg,
MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report
CERC-93-4

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers,
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield,
VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The purpose of the SUPERDUCK Beach Sediment Sample Experiment was to study beach response to storm waves. Data were collected during an 11-day experiment influenced by two extratropical storms. Daily beach profiles were surveyed along four lines to give a three-dimensional picture of beach response. Surface sediment samples were collected at the berm, upper swash, and lower swash to examine daily grain size distribution changes. Wave data collection from a wave gage located in 8 m of water provided changes in wave height and period during the two storms. The foreshore exhibited progressive daily erosion during the first 5 days of the experiment as the first storm event waned. The last 6 days showed a progressive accretion on the foreshore, even under the influence of the second storm. Most variability in daily sediment grain size distribution occurred in the upper swash, a zone of both uprush and backwash influence. Berm samples were finer and better sorted, deposited at the area of maximum uprush. Lower swash samples were coarser and more poorly sorted as the backwash interacted with incoming surf bores. Behavior of the foreshore was partially independent of waves as nearshore bathymetry appeared to play a dominant role in the erosion and accretion pattern.

14. SUBJECT TERMS

Beach profiles	Foreshore	SUPERDUCK
Beach sedimentation	Grain size distribution	
Extratropical storms	Profile sediment interaction	

15. NUMBER OF PAGES
49

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		